COST EFFECTIVENESS OF MARINE FIRE PROTECTION PROGRAMS

Final Report

November 1978

U. S. DEPARTMENT OF COMMERCE
Maritime Administration
National Fire Prevention and Control Administration
National Bureau of Standards

COST EFFECTIVENESS OF MARINE FIRE PROTECTION PROGRAMS

Final Report

November 1978

By:

Stanford Research Institute International

Kenneth R. Oppenheimer, Project Leader
Raymond S. Alger
Stanley B. Martin
Peter C. McNamee
Fred L. Offensend

Prepared for:

U. S. DEPARTMENT OF COMMERCE
Maritime Administration
National Fire Protection and Control Administration
National Bureau of Standards

This report presents the results of a cost-effectiveness study of alternative marine fire protection programs. The report includes an estimate of current and future marine fire losses and a comparison of the cost-effectiveness of programs designed to reduce these losses.

We estimate that current marine fire losses average $75 million per year. These losses include vessel, cargo, human, waterfront, and commercial losses resulting from fires aboard all merchant ships in U.S. ports and waters and U.S. flag merchant ships at sea and in foreign ports and waters. We also estimate that because of new trends in shipping, this average will grow to $100 million per year over the next 20 years if the current level of marine fire protection is maintained. However, new programs in marine fire protection, including tanker inerting, seamen firefighting training, and vessel traffic control, are now being or soon will be implemented; we estimate that these programs will reduce marine fire losses from what they would otherwise be to an average of $77 million per year during the period 1980-2000.

An additional marine fire protection program has been proposed in a bill before the U.S. House of Representatives. This bill proposes to establish regional marine firefighting teams in port cities throughout the country. In our analysis, we have developed a wide range of alternative approaches to compare with this regional team approach. These alternative approaches emphasize both fire prevention and fire suppression; they involve fire departments, the U.S. Coast Guard, merchant seamen, and fire protection equipment.

Specifically, eight fundamentally different strategic approaches for improving marine fire protection have been considered in this analysis. These eight programs are (1) developing a high level of expertise in marine firefighting among a small number of chiefs in fire departments of U.S. port cities, (2) developing a high level of expertise in marine firefighting in regional teams to be located in U.S. port cities, (3) developing a high level of expertise in marine firefighting in U.S. Coast Guard Reserve units in U.S. port cities, (4) providing low level training in marine firefighting to fire department personnel in U.S. port cities, (5) providing training in shipboard firefighting strategy, leadership, and use of built-in suppression systems to officers of U.S. flag ships, (6) providing brief instruction on the use of built-in fire suppression systems to officers on U.S. flag ships and foreign flag ships in U.S. ports, (7) redesigning built-in fire suppression systems to simplify their use, and (8) installing spray collars on pressurized fuel lines in engine rooms of U.S. flag ships to prevent a large fraction of engine room fires. All of these programs

and the hundreds of possible combinations of these programs are compared with the "status quo" alternative of maintaining the status quo level of marine fire protection.

To compare the cost-effectiveness of these alternative marine fire protection programs, we built a quantitative model of ship fires, firefighting performance, and fire losses. This model computes the expected net savings of each alternative, where expected net savings is defined as the expected reduction in losses (relative to the status quo) minus the expected cost of the program (relative to the status quo). The model relates firefighting performance in each type of ship fire to the extent of damage that occurs. It incorporates both historical data and consensus judgments of experts, and has been tested and calibrated on the basis of past ship fire data.

Our analysis indicates that the optimal program, the one with the highest expected net savings per year, is a combination of developing marine firefighting expertise and providing low level marine firefighting training in fire departments, providing training in shipboard firefighting strategy to officers of U.S. ships, installing spray collars in engine rooms of U.S. ships, and instructing ship officers on foreign ships in the use of built-in fire suppression systems.

Table ES-1 shows the expected net savings of each individual alternative and of a few selected combinations of alternatives, including the optimum. The net savings of a combination plan may be less than the sum of the savings of the individual plans because some of the savings may overlap. It should be noted that the inclusion of the Instruction on Built-in Systems plan in the optimal program is only marginally cost-effective; this fifth element of the optimal program should be studied more carefully before any plans for implementation are made. A ranking of alternatives on the basis of benefit-cost ratios is given in the text in the section entitled "Conclusions."

The sensitivity of the ranking of the alternatives to the key assumptions and critical judgments in the model was measured. When the most sensitive parameters were varied, the expected net savings of each of the most attractive alternatives moved in the same direction and by approximately the same amount. Therefore, we are confident of the ranking of the alternatives.

This analysis began as an evaluation of the legislation proposing the establishment of regional marine firefighting teams in U.S. port cities. The analysis has shown that the key idea embodied in this legislation--the development of marine firefighting expertise for land-based firefighters--is the backbone of each of the most cost-effective alternatives. However, the regional marine firefighting team program, with its full-time marine firefighters and detailed prefire plans, is not--either alone or in combination with other programs--as cost-effective as the program developing marine

Table ES-1

EXPECTED NET SAVINGS OF ALTERNATIVES AND SELECTED COMBINATIONS OF ALTERNATIVES (MILLIONS OF DOLLARS PER YEAR)

Marine Fire Protection Alternative	Expected Net Savings
Individual Alternatives	
Fire Chief Expertise	15.7
Regional Teams	15.0
Coast Guard Reserve Units	14.1
Fire Department Low Level Training	6.9
Ship Fire Officer	5.8
Instruction on Built-in Systems	5.1
Spray Collars in Engine Rooms	3.1
Redesign Built-in Systems	2.9
Maintain Status Quo	0.0
Selected Combinations of Alternatives	
Fire Chief Expertise + Fire Dept. Training + Ship Officer + Spray Collars + Instruct Built-in	23.6
Fire Chief Expertise + Fire Dept. Training + Ship Officer + Spray Collars	23.5
Coast Guard Reserve + Fire Dept. Training + Ship Officer + Spray Collars + Instruct Built-in	23.1
Regional Teams + Ship Officer + Spray Collars + Instruct Built-in	20.3
Fire Chief Expertise + Fire Dept. Training	17.9
Regional Teams + Spray Collars	16.8
Fire Dept. Training + Spray Collars	9.4

firefighting expertise within the existing framework of municipal fire departments. This latter plan achieves approximately the same expected reduction in losses as the regional team program, but at a much lower expected cost. In addition, the program organized within the existing framework of municipal fire departments has the advantage that it could easily be broadened in scope to provide firefighting expertise for all transportation and hazardous cargo fires rather than for ship fires alone.

CONTENTS

ILLUSTRATIONS

TABLES

ACKNOWLEDGEMENTS

Numerous individuals and organizations provided information without which we could not have performed this study. The names of each of the individuals who provided information useful to the analysis are listed as references at the end of the report. We would like to thank all those that helped us for their assistance.

Of the individuals listed, there were 10 who were extremely helpful and who played vitally important roles in providing us with expertise and data. In alphabetical order, they are: Commander William Ecker, Chief, Information and Analysis Staff, Office of Merchant Marine Safety, U.S. Coast Guard; Captain Robert Hansen, Seattle Fire Department; Mr. Ray Hicks, Claims Manager, The American Hull Insurance Syndicate; Assistant Chief W. Donald Jeffrey, Airport Fire Department, Massachusetts Port Authority; Instructor Dale Krabbenschmidt, Military Sealift Command Firefighting School, Treasure Island, California; Captain Carl Otterberg, Ship Management Officer, Western Region, Maritime Administration; Assistant Chief Robert Rose, Planning and Research Division, San Francisco Fire Department; Deputy Chief Thomas Rush, Marine Division, New York City Fire Department; Mr. Hubert Russell, Assistant Chief Engineer, Morris Guralnick Associates, Naval Architects and Engineers; and Mr. Allen Schumaker, President, The American Hull Insurance Syndicate. We owe a special note of gratitude to these 10 people.

In addition, we would like to thank the contracting officer's technical representatives, Mr. William Bovis of the Maritime Administration, and Mr. Edwin Hackett, formerly of the National Fire Protection and Control Administration and currently with the Maritime Administration, for their frequent assistance in identifying sources of information and in arranging the affairs of this project.

PART ONE

PRINCIPAL RESULTS

I INTRODUCTION

Background

In 1969, a serious fire broke out aboard a freighter at a dock in the port of Seattle. In fighting the fire, large quantities of water were applied without dewatering, and the vessel capsized.

After this incident, the Seattle Fire Department and the Washington State Commission for Vocational Education obtained funding from the Maritime Administration of the U.S. Department of Commerce to conduct a pilot program in the Puget Sound area to improve the level of marine fire protection. In this pilot program, a training curriculum in marine firefighting for members of the municipal fire departments was developed, prefire planning manuals for individual vessels were prepared, and a system of airlifting firefighters and equipment to vessels under way was devised.

During the 28 months of operation of the pilot program, there were no major ship fires in the Puget Sound area, but a few did occur in other areas of the country, the worst of which was a collision-caused explosion and fire involving two tankships at Marcus Hook, Pennsylvania. After the Marcus Hook fire, U.S. Congressman Forsythe of New Jersey drafted a bill, H.R. 11459, that proposed the establishment of regional marine firefighting teams, modeled after the Puget Sound pilot project, in port cities all across the nation. Various changes and amendments have been made and a revised version of the bill has been introduced, but the principal component is still the establishment of regional marine firefighting teams, modeled after the Puget Sound pilot project, on a nationwide basis.

Differences of opinion about the need to improve and the best way to improve marine fire protection existed among members of the House of Representatives' Committee on Merchant Marine and Fisheries, officials in the Maritime Administration, officials in the National Fire Protection and Control Administration, and key personnel who had been involved in the Puget Sound pilot program. Some of these disagreements concerned the magnitude of the current marine fire problem, while others centered on the choice between automatic fire suppression equipment and manual firefighting. In the latter case, there was disagreement whether special training ought to be directed toward municipal fire departments or toward merchant seamen. Other major differences of opinion concerned the cost-effectiveness both of the prefire manuals and of the system for airlifting land-based firefighters to vessels under way. Finally, the political and organizational aspects of the proposed regional teams and their interaction with local fire departments were of concern to members of the congressional committee and of the two federal agencies.

As a result of these major differences of opinion, the U.S. Department of Commerce, through the National Fire Protection and Control Administration, the Maritime Administration, and the National Bureau of Standards, contracted with SRI International to perform a cost-effectiveness study of the marine fire protection program proposed in H.R. 11459 and of possible alternative approaches to marine fire protection. The study began in August, 1977 and was completed in September, 1978. It was a joint effort of SRI's Decision Analysis Group and Fire Research Group. Dr. Kenneth Oppenheimer led the decision analysis task and Mr. Raymond Alger led the fire research task. Dr. Fred Offensend and Mr. Stanley Martin supervised these respective tasks. Dr. Peter McNamee of the Decision Analysis Group and Dr. Steve Wiersma of the Fire Research Group were the other principal staff members of the project. Several subcontractors and consultants, listed in the text of the report, were also engaged to provide specific informational needs.

The study consisted of two phases. Phase I was an examination of the entire marine fire problem and an analysis of the cost-effectiveness of individual marine fire protection programs. Preliminary results developed in Phase I showed the relative cost-effectivness of the individual programs, but more importantly identified the most critical areas in the analysis--those areas where further investigation was required. In Phase II, these critical areas were examined in depth and refined estimates of the cost-effectiveness of all individual programs and combinations of programs were made.

<u>Scope of the Analysis</u>

There were two principal tasks in this study: (1) estimating the magnitude of the current marine fire problem, and (2) comparing the cost-effectiveness of alternative marine fire protection programs. This comparison involved the generation of alternative marine firefighting plans to be compared with the H.R. 11459 proposal, and the measurement of the expected reduction in fire losses and increase in costs associated with each of the alternatives considered.

These alternative programs involve fundamentally different strategies to reduce marine fire losses. Some of the strategies emphasize fire prevention whereas others emphasize fire suppression. Some emphasize training people, either seamen or firemen, whereas others emphasize equipment. The analysis focuses on fundamentally different strategic approaches to improve marine fire protection. The organizational structure and day-to-day operation of each program are examined only insofar as necessary to measure the expected reduction in loss and increase in cost relative to the status quo. In an analysis of this kind, there is no need to expend great effort to obtain precise dollar losses. What is needed is a level of detail and a level of accuracy sufficient to distinguish properly the cost-effectiveness of the alternative marine fire protection strategies considered.

The net savings we calculate in this analysis are savings to society as a whole. The distributional question of who pays the costs and who enjoys the benefits of a new program should be debated only after the most cost-effective program is identified.

The time frame over which the alternative strategies are compared is 1980-2000. Therefore, trends and programs expected to affect the marine fire problem over the next 20 years, independent of the alternatives, must be projected for the base case.

The sponsoring agencies defined the scope of the problem to include fires aboard all merchant vessels in U.S. ports and waters, and aboard all U.S. flag merchant vessels at sea and in foreign ports and waters. Fires aboard foreign flag vessels at sea and in foreign ports and waters are not included. All types and sizes of merchant vessels are included, from fishing boats to supertankers. Military vessels and small pleasure craft are not included. The losses we are considering include damage to the vessel, cargo, pier, and waterfront facilities; human death and injury; pollution, cleanup and salvage costs; fire suppression costs; unemployment, disruption of business, and loss of commerce. The sponsoring agencies indicated that in measuring losses, damage to foreign ships and deaths of foreign crew members when in U.S. ports and waters were to be treated on the same basis as damage to American ships and crews.

Attention was given in this study to all fires aboard merchant vessels, both those that are reported and those that are unreported. The reported fires include fires, explosions, and collisions resulting in fire in which property damage exceeds $1,500 or where there is a human death or injury incapacitating someone for at least 72 hours; by law, these vessel fires must be reported to the U.S. Coast Guard. We have not attempted, however, to estimate losses for the unreported fires. Even if the number of unreported fires far exceeded Coast Guard estimates, the losses in these cases are so small compared to those in reported fires that they would hardly affect the total losses from all ship fires. Finally, pier fires where no ship is involved are not included; fire damage to piers is included in cases where a burning ship communicates fire to the pier or where a burning pier communicates fire to a ship. A survey of major port city fire departments revealed that they were adequately prepared to protect pier structures and that the part of the marine fire problem of most concern was the fire aboard the vessel.

Method of Approach

As indicated, there are numerous possible programs that could reduce marine fire losses. Some of these programs emphasize fire prevention as opposed to fire suppression; some emphasize people as opposed to equipment. Our approach in evaluating and comparing alternative programs is to assess the costs and fire-related losses that

would occur under each program and to select the program that provides the greatest net savings, where net savings is measured as the difference between the reductions in losses and the increases in costs.

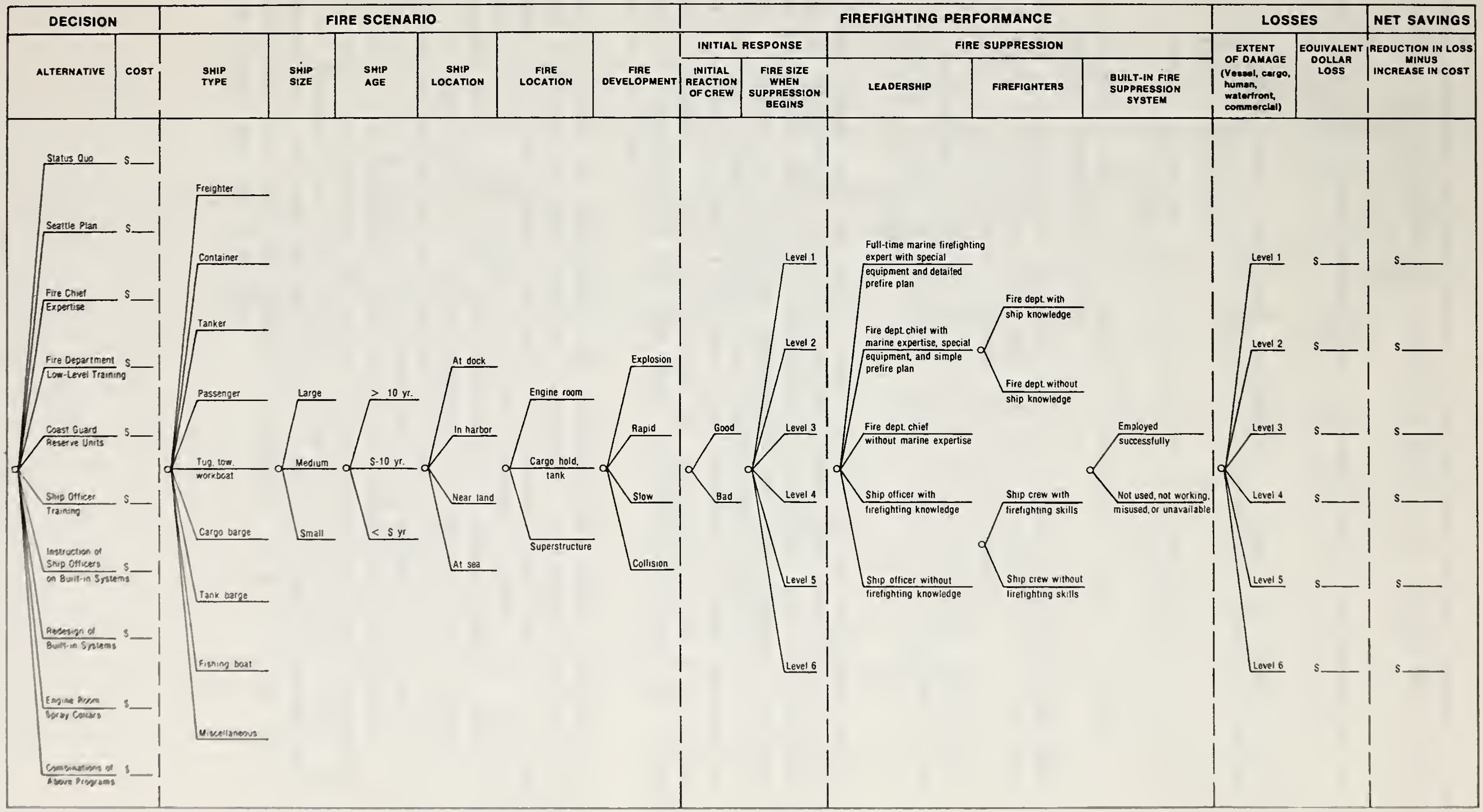
Very little historical data exists for assessing the losses that would occur under each program. Some of the programs have been in operation in a few ports for many years; one program has been tried in the Puget Sound area for two years; some have been in effect with several shipping lines for various lengths of time; and some have never been implemented. The number of ship fires that have occurred in situations where any one of these programs was in effect is very small; it is therefore not possible, on the basis of historical data alone, to make a meaningful estimate of the amount by which fire losses could be reduced if one of these programs was implemented nationwide. Nevertheless, planning decisions must be made today, and a systematic attempt must be made, using the best information available, to assess the costs and losses that can be expected to occur under each alternative.

We use a decision analysis approach to assess these costs and losses. Decision analysis is a methodology for evaluating complex decision problems involving uncertainty. The methodology uses quantitative models, often taking the form of the decision tree in Figure I-1, to assess systematically the consequences of each decision alternative. The models incorporate both historical data and expert judgment expressed quantitatively in the form of probabilities. The methodology therefore serves as a vehicle for integrating the various kinds of information available to assess the effectiveness of the alternative marine fire protection programs.

Figure I-1 shows the decision tree developed for this analysis. A simple tutorial example explaining how such a decision tree is used is presented at the end of this chapter in the section entitled "Tutorial Example of the Decision Analysis Methodology." The first column in Figure I-1 identifies the set of decision alternatives and their costs; each alternative, both individually and in combination with others, was analyzed in this study. The next section of the tree specifies the fire scenarios: the number of fires per year for all types of ships, classified in nine groups, followed by the probability of fires by ship size and age, by location of the ship when the fire occurs, by location of the fire aboard the ship, and by fire development. Specification of these elements is essential in assessing the effectiveness of the firefighting effort and in placing a value on fire damage.

The third section of the tree provides the framework for assessing firefighting performance. This assessment depends on the expertise of the leadership, the training of the firefighters, and the equipment they can deploy. The sets of branches included in the firefighting performance section provide a framework for measuring the effectiveness of the firefighting effort by tracing the fire from its initial size when firefighting begins to the full extent of damage when the fire is extinguished. Finally, the vessel, cargo, human, waterfront, and

FIGURE I-1 DECISION TREE FOR EVALUATING MARINE FIRE PROTECTION PROGRAMS



commercial damages are converted to equivalent dollar losses. The net savings are then computed by comparing costs and losses with the status quo.

The decision tree shows the informational requirements of this analysis:

(1) Descriptions and cost estimates of each alternative, in particular how they affect the status quo level of marine fire protection.

(2) Probabilities of each possible combination of fire scenario elements.

(3) Descriptions of the range of sizes of fires and extents of damage from ship fires.

(4)(a) Probabilities of each type of crew response and each type of firefighting team and (b) a set of rules relating initial fire size to final extent of damage.

(5) Valuation procedures for establishing the equivalent dollar loss of vessel, cargo, human, waterfront, and commercial damage.

It is very important to note that the decision analysis guides the information-gathering activity rather than the availability of data guiding the analysis. All information required for the analysis was gathered. Often, no data was available for the parameter in question; in such cases, expert judgment was quantified instead. In all cases, the best information available was used whether it was historical data or expert judgment. The philosophy is that decisions must be made in the face of uncertainty and the best information should be brought to bear on the decision.

As the list of informational requirements above indicates, there are five fundamental parts to the analysis. A separate model, as shown in Figure I-2, was built for each of these five parts: a decision alternative and cost model, a fire scenario model, a firefighting performance model, a fire involvement and damage model, and a value model. These models, taken together, provide the framework for estimating the expected net savings of each decision alternative. They do so by specifying the cost of each decision alternative and the effect each decision alternative has on firefighting performance. The firefighting performance in these fire scenarios then determines the extent of damage from ship fires. Finally, the value model converts this damage to the equivalent dollar loss for that alternative. The cost and loss for each alternative, compared with that for the status quo, determine the net savings.

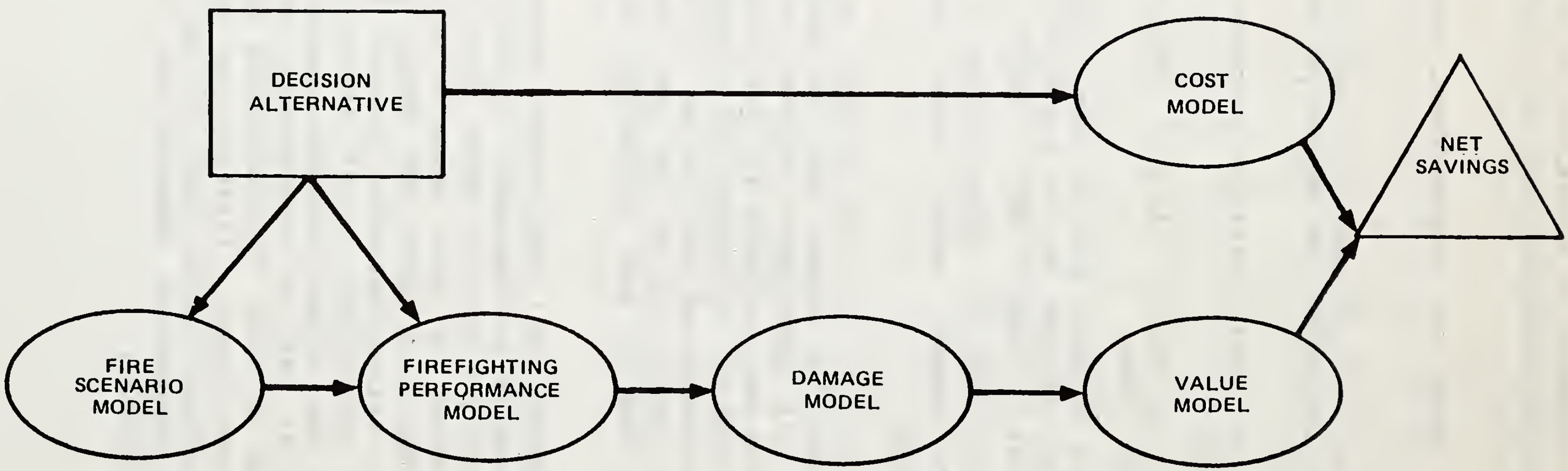


FIGURE I-2 SYSTEMS MODEL FOR CALCULATING NET SAVINGS

Organization of This Report

This report is organized in two parts, the first part providing a summary of our principal results and the second part providing a detailed desciption of our methodology and data. Part One includes:

(1) The introduction and a tutorial example of the methodology (Chapter I).

(2) An analysis of marine fire losses as of 1975; a brief description of the current marine fire protection system; changes in the system expected to occur over the next 20 years, and expected losses under the status quo alternative, 1980-2000 (Chapter II).

(3) A brief description of the alternative marine fire protection programs aimed at reducing losses (Chapter III).

(4) A comparison of the cost-effectiveness of these alternatives (Chapter IV).

(5) The conclusions (Chapter V).

Part Two includes the methodology and data, organized by the five component models:

(6) The Fire Scenario Model (Chapter VI).

(7) The Fire Involvement and Damage Model (Chapter VII).

(8) The Value Model (Chapter VIII).

(9) The Firefighting Performance Model (Chapter IX).

(10) The Decision Alternatives and Cost Model (Chapter X).

Part One may be read as a self-contained report, with reference to the supporting data in the second part as desired. Only after Part One is read are the chapters of Part Two placed in perspective so that they may also be read as self-contained units. Together, Parts One and Two provide a summary of all principal results and a complete documentation of the methodology and data supporting them.

The decision analysis approach is best explained with a tutorial example. The example that follows introduces many of the concepts that are used in assessing the effectiveness of the various marine fire protection programs. Readers interested only in the results of our analysis and not in the methodology may skip the tutorial example and resume the text at the beginning of Chapter II.

TUTORIAL EXAMPLE OF THE DECISION ANALYSIS METHODOLOGY

Suppose, for the purpose of this tutorial example only, that the scope of the study is limited to tank barge fires that occurred in U.S. ports. Suppose further that the only loss category of interest is damage to the vessel itself, and that the only alternative being considered is whether the municipal fire departments in all U.S. port cities should develop a specialized marine fire training program for their officers and firefighters at an annual amortized cost of $80,000 for the next 20 years.

Step 1: Establishing the Status Quo, 1975

The first step in the analysis is to establish the average annual loss in the past. Let us assume that the records of all ship fires for the years 1966-1975 were available. The average annual loss for this 10-year period, when adjusted for inflation, provides an estimate of average annual losses which we call the "status quo, 1975." To establish this status quo or base case, let us assume that when the past 10 years of ship fire records were examined, we found that there were 60 tank barge fires in U.S. ports, of which 42 (70%) were minor fires and 18 (30%) were major fires. Let us also assume that when adjusted for inflation to yield 1975 dollars, the average loss per fire for minor fires was $30,000 and for major fires was $150,000. Figure I-3 is a simple probability tree for use in measuring the average annual loss. The computation using the probability tree proceeds as follows:

```
  .70 x $ 30,000
+ .30 x $150,000
$ 66,000 per fire (average)
x              6 fires per year (average)
$396,000 average annual loss
```

To measure the reduction in losses expected from implementing the fire department training program, we need to elaborate this probability tree to provide a description of the performance of the current or "status quo" marine fire protection system. In particular, for this example, we need to specify (1) the size of each fire when firefighting began, (2) the level of training of those who fought the fire, and (3) the extent of damage when the fire was extinguished. Let us assume that by examining fire records and by interviewing marine firefighting experts, we were able to gather these 3 data items for each fire (as shown in Figure I-4).

Figure I-4 specifies whether the six fires per year started as small or large fires, whether they were extinguished by the tank barge crew or by a fire department with or without specialized marine firefighting training, and whether the ultimate damages from the fires

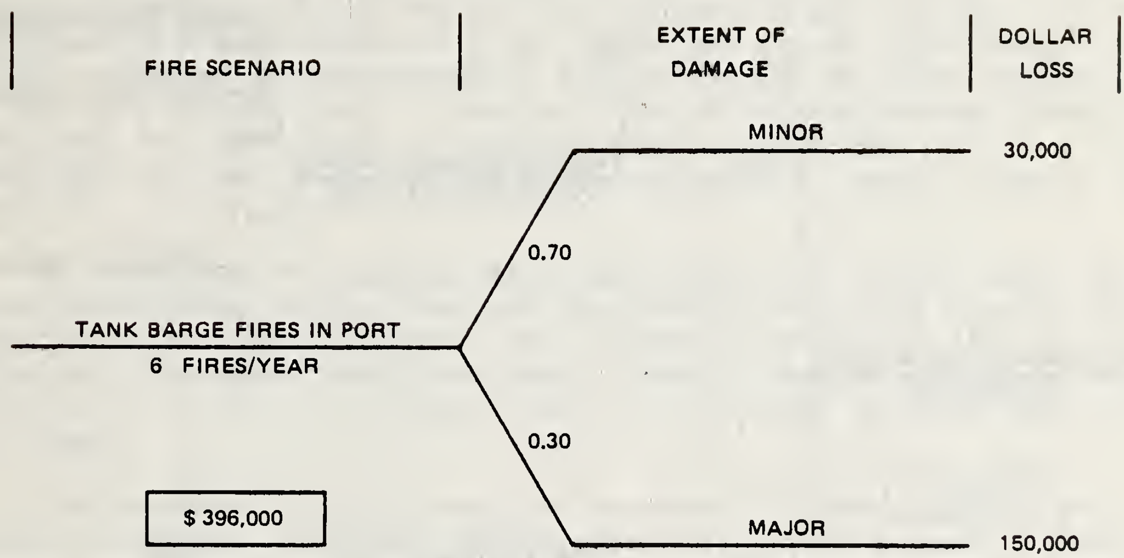


FIGURE I-3 TANK BARGE TUTORIAL: LOSS DISTRIBUTION, STATUS QUO, 1975

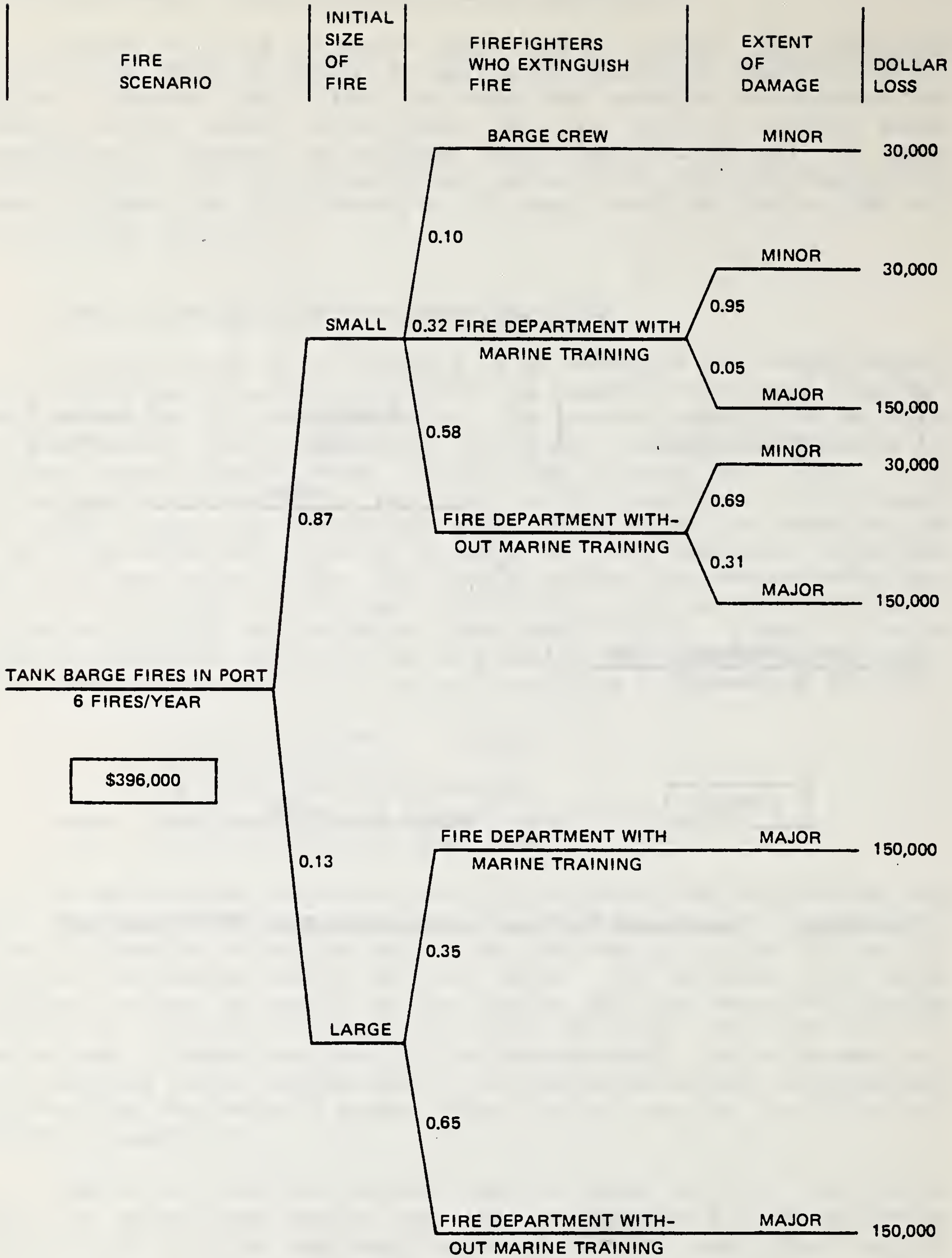


FIGURE I-4 TANK BARGE TUTORIAL: LOSSES RELATED TO FIRE PROTECTION SYSTEM, STATUS QUO, 1975

were minor or major. Each of the numbers at the forking of the branches of the tree is the probability of the characteristic described. For example, 87% of the six fires per year started small, perhaps from spills while loading oil or from a pumping system ignition; 13% of the fires started large, either as explosions in empty tanks or fires erupting after a collision with another vessel. Of the fires that started small, Figure I-4 shows that 10% were extinguished by the crew prior to the arrival of the fire department, 58% were fought by municipal fire departments without special marine fire training, and 32% were fought by municipal (or port authority) fire departments with specialized marine fire training.

In the fires that started small, the final set of branches shows that when the crew was able to extinguish the fire, it always remained small and caused only minor damage, on the average $30,000; when a fire department without special marine fire training fought the fire, it was contained in a small section of the vessel and caused minor damage 69% of the time, but spread throughout the vessel causing major damage 31% of the time; finally, when a specially trained fire department fought a fire that started small, it was contained, with damage kept at a low level 95% of the time, and only 5% resulted in major damages of $150,000.

The lower set of branches shows that fires that started large were never extinguished by the crew and were fought 35% of the time by fire departments with special marine fire training and 65% of the time by departments without such training. However, major damage always resulted in either case, because most of the damage was done when the fire began.

The procedure of taking weighted averages to compute average annual losses is used for the tree in Figure I-4, just as it was used in Figure I-3. Here, however, the computation process takes several steps: first, for fires that start small, the expected loss is

$$\begin{array}{l} \quad 0.10 \times \$30,000 \\ \quad 0.32 \times [(0.95 \times \$30,000) + (0.05 \times \$150,000)] \\ \underline{+\ 0.58 \times [(0.69 \times \$30,000) + (0.31 \times \$150,000)]} \\ \qquad\qquad \$53,496 \end{array}$$

Second, for fires that start large, the expected loss is

$$\begin{array}{l} \quad 0.35 \times \$150,000 \\ \underline{+\ 0.65 \times \$150,000} \\ \qquad\quad \$150,000 \end{array}$$

Taking the weighted average of these conditional expected losses, we find an expected loss per fire of

$$\begin{array}{r} 0.87 \times \$\ 53{,}496 \\ \underline{+\ 0.13 \times \$150{,}000} \\ \$\ 66{,}000 \end{array}$$

which, when multiplied by six fires per year, reproduces the status quo estimate of $396,000 per year.

Step 2: Establishing the Status Quo, 1980-2000

Figure I-4 provides a framework for measuring the reduction in losses from a special training program for fire departments if the future trends in shipping and marine fire protection were to reflect past conditions. However, several changes will be taking place regardless of whether the fire department training program is adopted. These changes must be incorporated in the "status quo" or base case against which the fire department training program is compared. Let us assume in this simple example that the only expected changes relevant for tank barge fires in U.S. ports are:

(a) A projected 18% increase in the number of tank barges operating in U.S. ports.

(b) A Coast Guard tankerman rating requirement for all flammable liquid transfer personnel on tank barges.

Let us assume that a marine fire expert predicts that the tankerman rating requirement will, because of greater care in loading and unloading operations, reduce the number of tank barge fires in port; he predicts that 20% of the small fires and 5% of explosions or large fires will be prevented. This expert also expects the tankerman rating requirement will enable the crew, because of their improved firefighting training, to raise to 30% the percentage of fires they extinguish before the fire department arrives.

Figure I-5 incorporates these future changes to produce the expected status quo, 1980-2000. The 5.81 fires per year take into account (1) the prevention of 20% of the 5.22 fires that start small and the prevention of 5% of the 0.78 fires that start large (giving a total of 4.92 fires per year), and (2) the 18% increase in the number of tank barges and hence, by assumption, the number of tank barge fires (1.18 x 4.92 = 5.81). After eliminating the prevented fires, we find that 85% of the fires will start small and 15% will start large (by explosion or collision). The only other change in Figure I-5 is the increase in the number of small fires the crew will extinguish themselves before the fire department arrives. Using the same weighted average procedure to evaluate the tree, we find the expected annual loss for the status quo, 1980-2000, is $332,355.

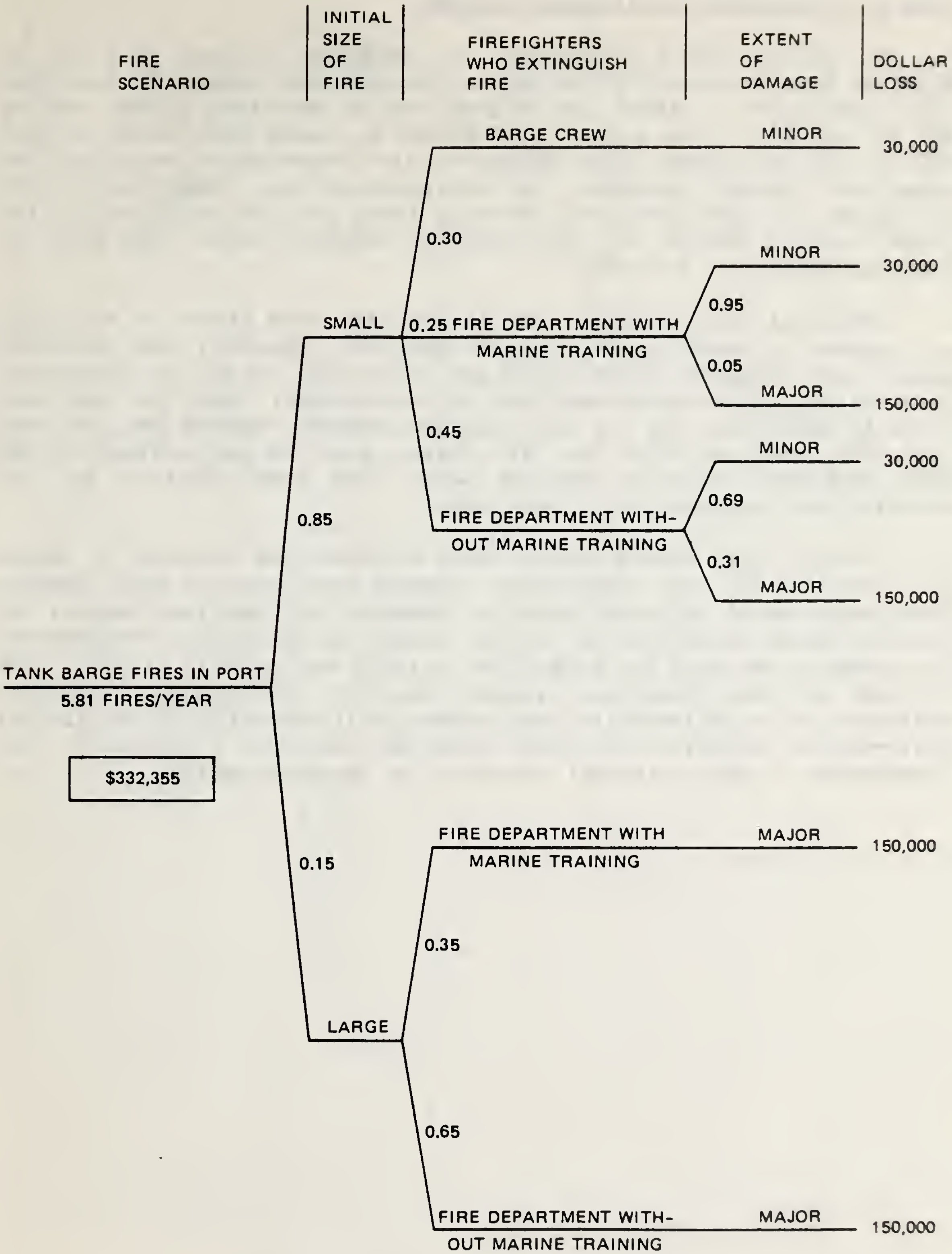


FIGURE I-5 TANK BARGE TUTORIAL: LOSSES RELATED TO FIRE PROTECTION SYSTEM, STATUS QUO, 1980-2000

Step 3: Evaluating the Training Program

We are now ready to measure the reduction in loss that can be expected from implementing the marine fire training program in municipal fire departments. Assume the program has an amortized annual cost of $80,000 and will train enough firefighters in enough port cities so that 90% of all tank barge fires fought by fire departments are fought by those with special training. By incorporating this change in the tree in Figure I-6 (90% for fires starting large and 90% x 70% = 63% for fires starting small), we find that the expected annual loss with the training program is $299,622.

Comparing this expected loss to the base case figure of $332,335, we compute a reduction in loss of $32,733. However, the increased annual cost relative to the status quo is $80,000, so the net savings is negative and the program would not be recommended. Note how important it is to incorporate in the base case the expected changes for the years 1980-2000; compared with the 1975 status quo, the net savings of the fire department training program would have been positive and the opposite decision would have been made.

Clearly, this simple example underestimates the benefits of marine fire training for fire departments, because such training would improve their performance in fires aboard all vessels, not just tank barges, and because other categories of losses should be included. Furthermore, this example was much too simplified to yield any reliable results. The purpose of this tutorial example was not, however, a realistic evaluation of an alternative, but rather an illustration of the kind of information required in this analysis and the methodology for integrating it into a logical structure for decision making.

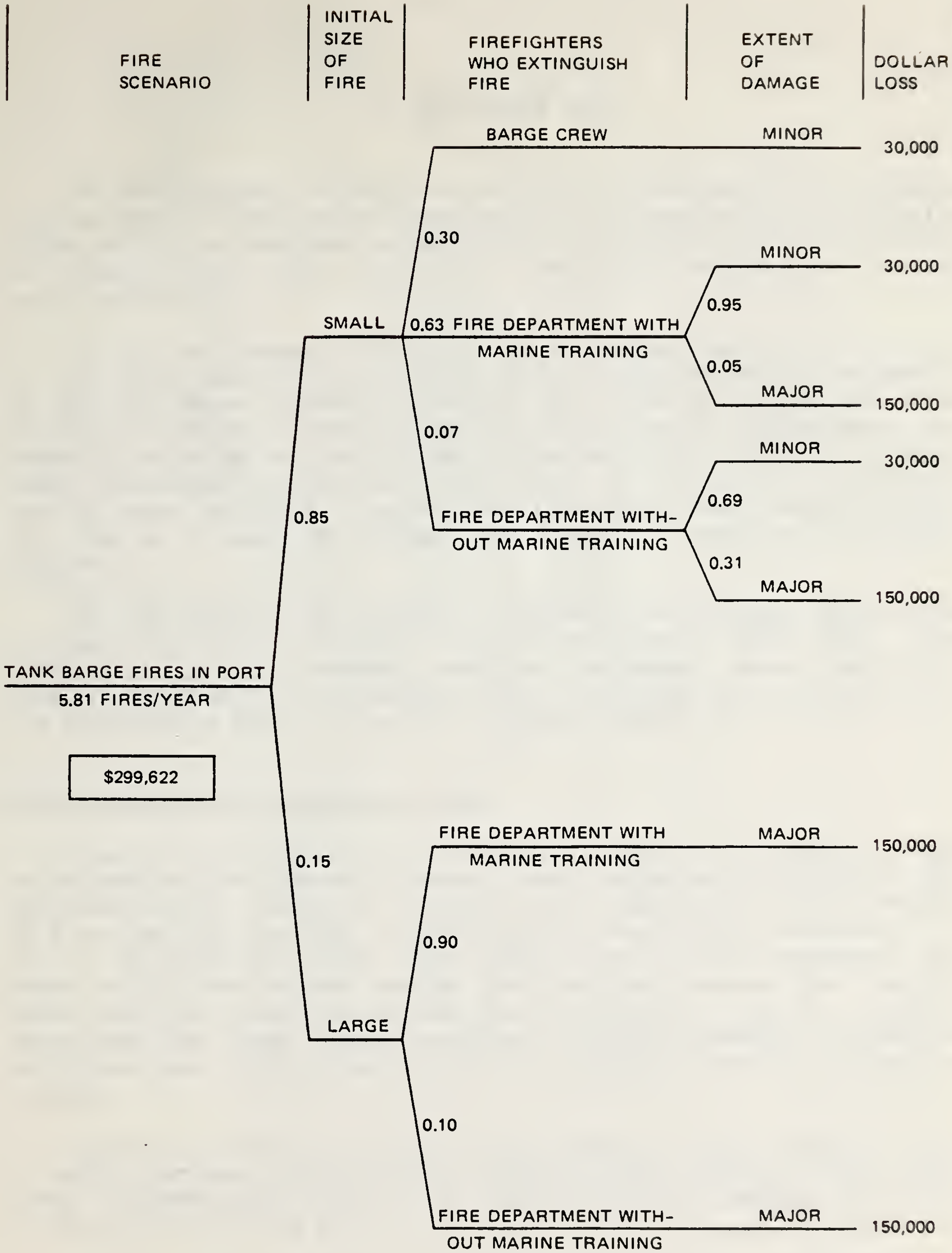


FIGURE I-6 TANK BARGE TUTORIAL: LOSSES UNDER MARINE FIRE TRAINING PROGRAM, 1980-2000

II THE STATUS QUO

In this chapter, we analyze past and current marine fire losses, examine current and future developments in the marine fire protection system and in the maritime industry that will affect future fire losses, and estimate fire losses under the "status quo" alternative for the years 1980-2000.

It is a surprisingly difficult task to estimate marine fire losses. The available records do not furnish reliable figures for all categories of loss, and hence a detailed model of ship fires and losses had to be developed to estimate those figures that were missing. Furthermore, new trends in shipping and new programs in marine fire protection currently being implemented will affect losses under the status quo alternative for the years 1980-2000. The full-scale decision tree, shown in Figure I-1, had to be used to estimate the effect of these new trends and programs.

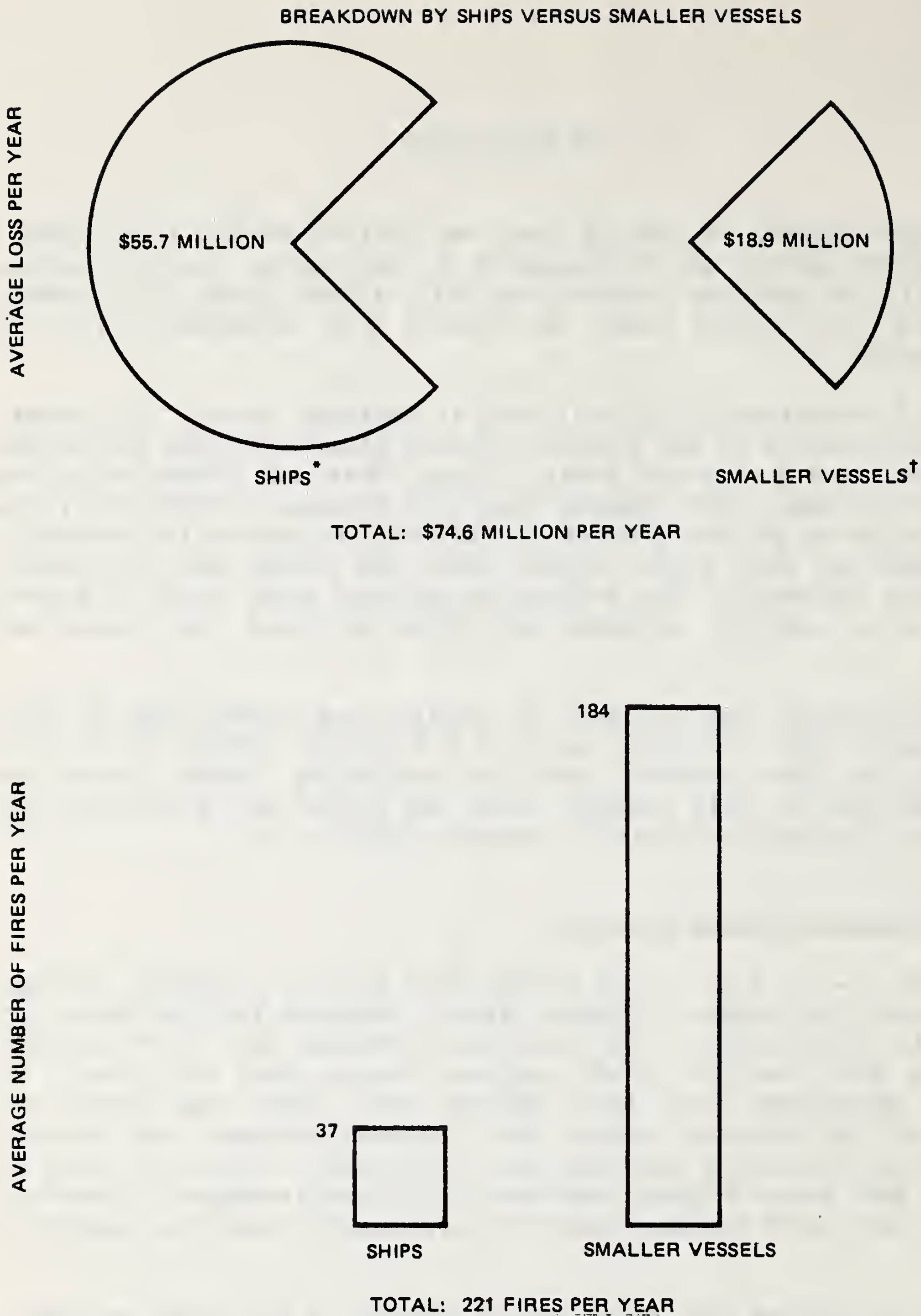
In the section that follows, we examine the current marine fire problem and that expected during the years 1980-2000. The methodology and data sources used for estimating those losses are briefly described in this chapter after the losses are presented, and are described in depth in Part II, Chapters VI-IX.

Marine Fire Losses, Status Quo, 1975

Figures II-1 and II-2 and Tables II-1 and II-2 present average annual marine fire losses in recent years, adjusted for inflation and expressed in 1975 dollars. We label them "Status Quo, 1975" because 1975 is the last year for which complete records were available. It should be emphasized that this "Status Quo, 1975" represents the magnitude of the current marine fire problem averaged over several years, not the losses for calendar year 1975 alone. It should also be emphasized that these figures represent long-term averages. Losses in any single year could be much larger or much smaller than this long-term average.

Figure II-1 shows that there are an average of 221 fires per year, 37 aboard merchant ships and 184 aboard smaller vessels. The 37 ship fires, representing only 17% of all the fires, account for $55.7 million, or 75% of the loss.

We have estimated that a ship fire causes a port catastrophe, on the average, once every 80 years (see Chapter IX). This type of port catastrophe, similar to the Texas City disaster of 1947, is a rare but



*Ships include freighters, bulk carriers, containerships, tankers, ro-ro, and passenger ships; military ships excluded.

†Smaller vessels include tank barges, cargo barges, fishing boats, tugboats, towboats, utility vessels, and miscellaneous craft; small pleasure craft excluded.

FIGURE II-1 MARINE FIRE LOSSES, STATUS QUO, 1975

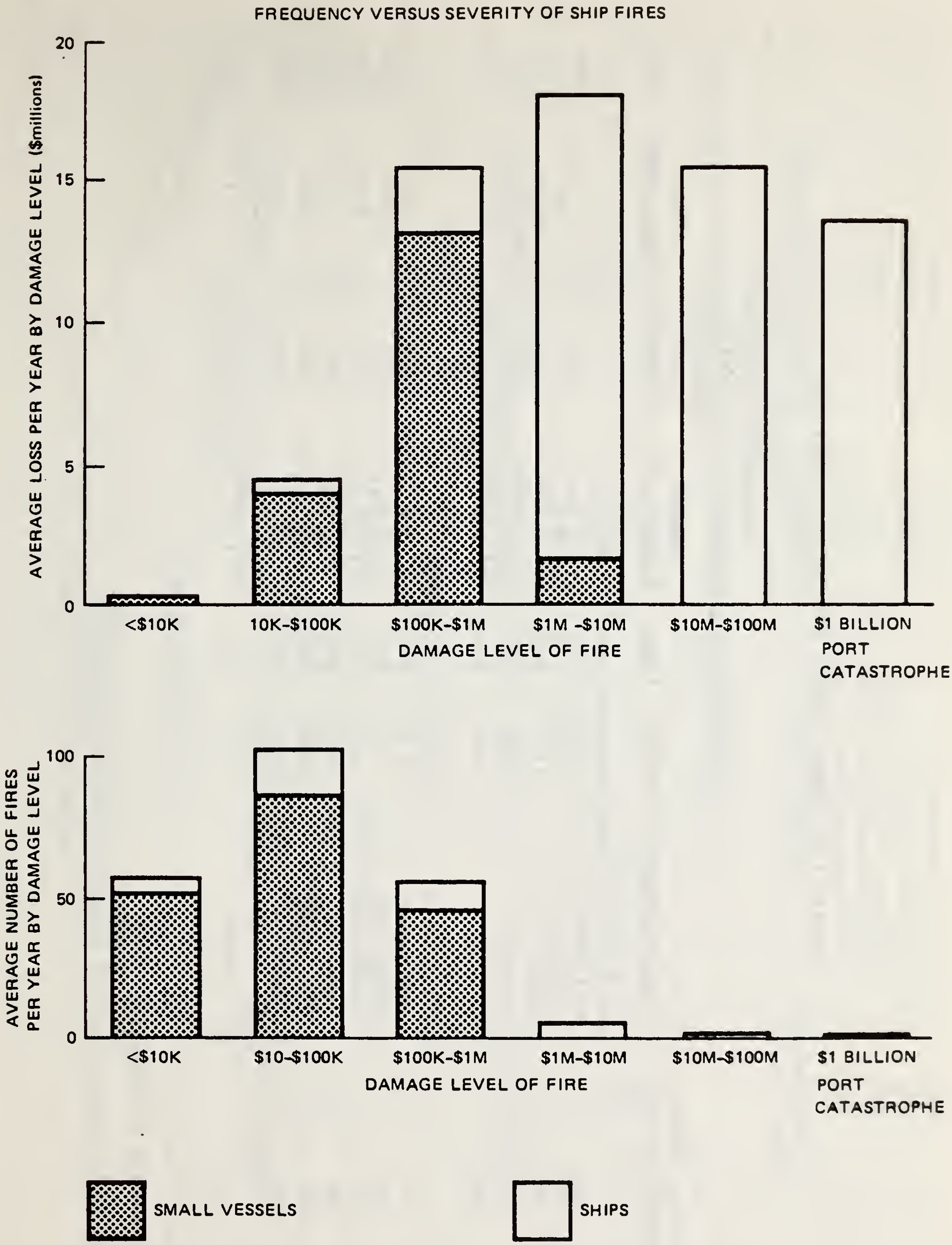


FIGURE II-2 MARINE FIRE LOSSES, STATUS QUO, 1975

Table II-1

MARINE FIRE LOSSES, STATUS QUO, 1975, BY SHIP TYPE

Average Number of Fires per Year	Type of Vessel	Average Loss per Year (millions of dollars): Vessel	Cargo	Human Death/Injury	Waterfront and Commercial	Port Catastrophe	Total
	Ships*						
22.4	Freighter	9.9	2.2	7.2† 2.5 10.6	1.0	2.4	18.0
3.3	Container	2.9	1.9	1.0 0.3 1.5	0.1	0.2	5.4
10.1	Tanker	11.6	1.4	11.2 3.6 6.3	4.6	10.6	31.8
1.4	Passenger	0.2	0.1	0.5 0.2 0.8	0.0	0.0	0.5
37.2	All ships	24.6	5.6	19.9 6.6 19.2	5.7	13.2	55.7
	Small vessels						
11	Tank barge	1.4	0.2	2.2 0.8 4.7	1.5	0.0	3.9
9	Cargo barge	0.2	0.2	0.7 0.3 1.7	0.0	0.0	0.7
80	Fishing boat	4.0	0.0	4.6 1.6 8.8	0.0	0.0	5.6
50	Tug, tow, utility	4.7	0.0	4.7 1.6 6.6	0.0	0.0	6.3
34	Miscellaneous	2.2	0.0	0.2 0.2 3.5	0.0	0.0	2.4
184	All small vessels	12.5	0.4	12.4 4.5 25.3	1.5	0.0	18.9
221	All vessels	37.1	6.0	32.3 11.1 44.5	7.2	13.2	74.6

*Categories as defined in text.

†The small numerals are the number of deaths and injuries.

Table II-2

MARINE FIRE LOSSES, STATUS QUO, 1975,
BY SHIP LOCATION, FIRE LOCATION, AND FIRE DEVELOPMENT
(Ships Only)

Breakdown by Ship Location

Average Number of Fires per Year	Ship Location	Average Loss per Year (millions of dollars) All Categories	Average Loss per Year (millions of dollars) Excluding Port Catastrophe
20.9	At dock	34.0	21.4
6.0	In harbor or near land	14.1	13.5
10.3	At sea	7.6	7.6
37.2	All ship locations	55.7	42.5

Breakdown by Fire Location

Average Number of Fires per Year	Fire Location	Average Loss per Year (millions of dollars) All Categories	Average Loss per Year (millions of dollars) Excluding Port Catastrophe
13.5	Engine room	15.6	14.1
10.0	Cargo hold (dry cargo vessels)	8.6	6.0
3.3	Cargo tank (tankers, includes LNG)	25.2	15.5
5.4	Superstructure	6.3	6.9
37.2	All fire locations	55.7	42.5

Breakdown by Fire Development

Average Number of Fires per Year	Fire Development	Average Loss per Year (millions of dollars) All Categories	Average Loss per Year (millions of dollars) Excluding Port Catastrophe
1.0	Tanker cargo explosions	17.3	9.8
5.4	Engine room explosions	7.1	6.4
1.0	Collisions resulting in fire	9.5	7.9
29.8	All others	21.8	18.4
37.2	All fire developments	55.7	42.5

devastating event. It contributes a significant amount to long-term average marine fire losses. Table II-1 provides a detailed breakdown of fires and losses by type of vessel and category of loss. In this table, the losses associated with the port catastrophe are listed separately to illustrate the relative importance of the port catastrophe in the total marine fire problem. Clearly, losses in a port catastrophe consist of vessel, cargo, human, waterfront, and commercial losses.

It is immediately noticeable from Table II-1 that vessel loss far exceeds cargo loss and is the major component of losses for each type of vessel. Such a result should not be too surprising because many of the worst fires and explosions occur in empty cargo tanks or in engine rooms, and little or no cargo is involved. One also observes that tanker fires comprise only 5% of the fires, but account for 43% of the losses. Tankers and freighters together account for 15% of the fires and 67% of the losses.

Figure II-2 shows graphically that a few big fires account for a huge share of the loss; specifically, 3% of the fires, all involving ships, account for 62% of the losses. As can be seen in these tables and figures, the same pattern of results still holds, though to a somewhat lesser extent, when the $13.2 million contribution from the port catastrophe is excluded.

Finally, Table II-2 gives three breakdowns of the $55.7 million loss for merchant ships only, excluding the smaller vessels. The first breakdown, by ship location, shows that ship fires at dock make up 61% of the losses; fires at sea make up only 14%. The reasons for the much larger percentage of losses at dock are (1) all merchant ships, both U.S. and foreign flag, are included when in U.S. ports and waters, but only U.S. flag ships are included at sea, and (2) ship fires at dock can destroy valuable waterfront facilities and can cause a port catastrophe, whereas even the worst ship fire at sea can destroy only the ship, its crew, and its cargo.

The second breakdown in Table II-2, by fire location, shows what types of ship fires are most frequent and what types do the most damage. Just 3.3 tanker cargo space fires, or 9% of the 37.2 ship fires per year, account for 45% of the losses (for ships only). One-half of the fires take place in the engine room and account for 28% of the losses. The final column of numbers shows that engine room and tanker cargo fires make up nearly equal parts of the loss if the port catastrophe is excluded.

The third breakdown in Table II-2, by fire development, shows that explosions in tanker cargo spaces and collisions resulting in fire (all of which involve a tank vessel) cause, on the average, the worst fires. An average of one cargo tank explosion per year and one collision involving a tank vessel every 2 years (two ships involved) accounts for 48% of all losses. The other single type of fire accounting for much of the losses is the engine room explosion, making up 13% of all losses.

These four figures and tables present in a concise form several informative summaries of the status quo, 1975 marine fire losses. They focus attention on the small fraction of fires that result in a large fraction of losses. It is particularly for these fires that one would want to develop improved fire prevention and control methods. Additional breakdowns of fires by age and size of vessel are included in Chapter VI, The Fire Scenario Model.

Figure II-3 shows the geographic distribution of ship fires by region, based on 14 years of Coast Guard statistics. Also indicated on this map are the locations of the 17 ship fires that occurred during the 10-year period 1967-1976, in which total damages exceeded $3,000,000 per fire (adjusted for inflation and expressed in 1975 dollars, and including $300,000 per death; for discusssion of this dollar value for human death, see Chapter VIII). It is interesting to note that more than half of these 17 largest loss fires have occurred in or near New Orleans, New York, and Philadelphia.

Marine Fire Losses, Status Quo, 1980-2000

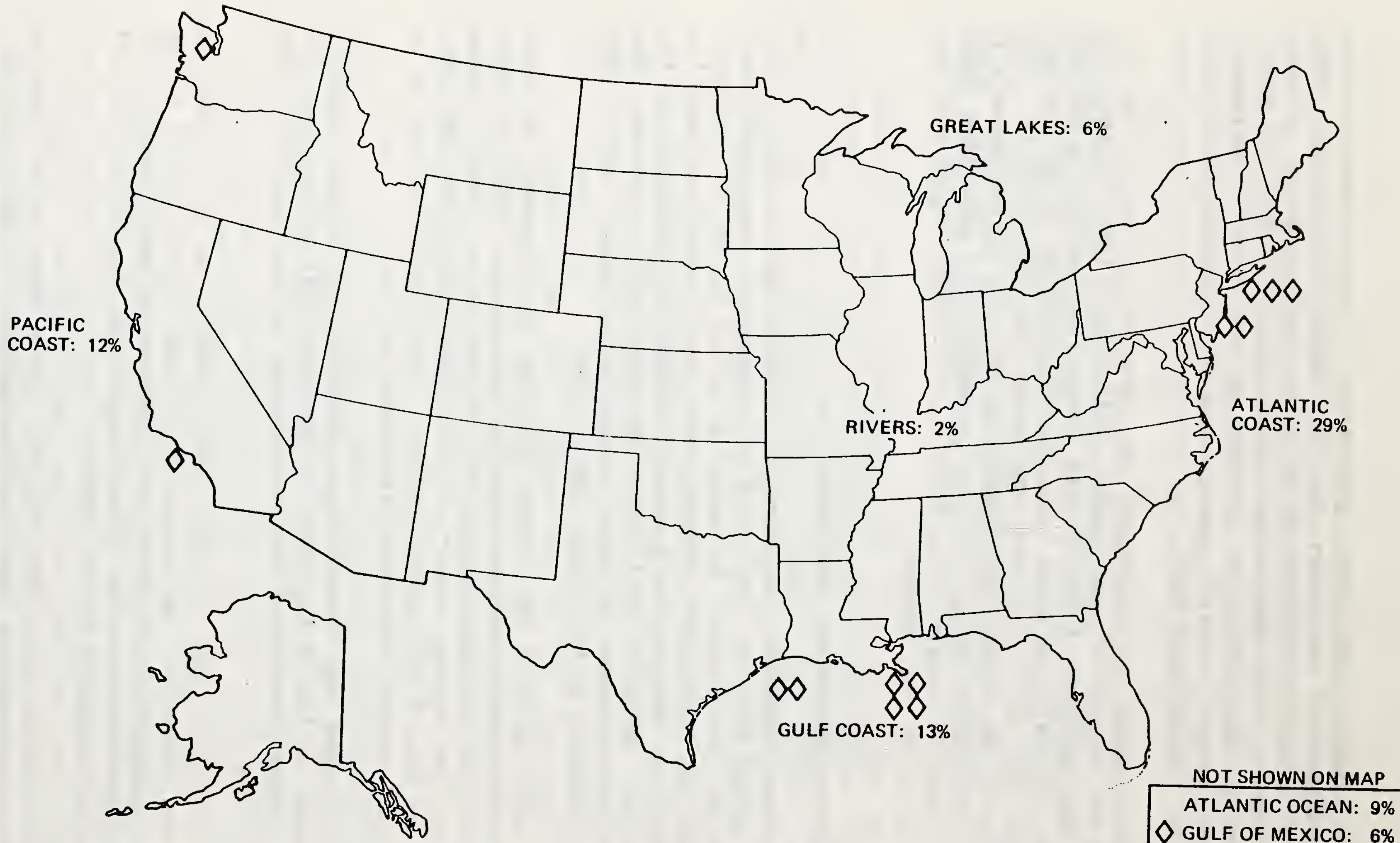
For the years 1980-2000, new trends in shipping and new marine fire protection programs that are just being initiated will have significant effects on marine fire losses. As explained at the end of this chapter, however, these new trends and programs have nearly equal and opposite effects on the total marine fire problem; therefore, average losses for 1980-2000 do not differ markedly from those of 1975. However, the composition of these losses by ship type and fire location does change significantly as shown in the tables that follow.

Figures II-4 and II-5 and Tables II-3 and II-4 present the same analysis of the marine fire losses for the status quo, 1980-2000 that was presented in the previous section for the status quo, 1975. Figure II-4 shows that the average number of fires increases to 261 per year, 52 of which are aboard the larger vessels. These 52 fires, making up 20% of the total, account for 71% of all losses.

Table II-3 shows that vessel damage remains the largest component of losses, making up 49% of the total for ships and 53% of the total for all vessels. Tankers make up 28% of all losses, reduced from 43% in the status quo, 1975.

Figure II-5 shows the frequency versus severity of ship fires for the status quo, 1980-2000. The pattern is similar to that of the status quo, 1975, but somewhat more accentuated because of the possibility of the LNG port catastrophe; in the future status quo, we estimate that 3% of the fires will cause 67% of the losses.

Table II-4 shows the losses for ship fires only, broken down by ship location, fire location, and fire development. In the status quo, 1980-2000, there is a slight decrease in the percentage of losses at



LEGEND

The numbers indicate the percentage by region of all reported fires on all merchant ships included in this study. The ◇s mark the locations of the ship fires, occurring from 1967-1976, in which total damages exceeded $3,000,000 (adjusted for inflation to 1975 dollars and including $300,000 per death). In collision fires, 2◇s are marked if damages associated with each vessel exceeded $3,000,000.

FIGURE II-3 GEOGRAPHIC DISTRIBUTION OF SHIP FIRES

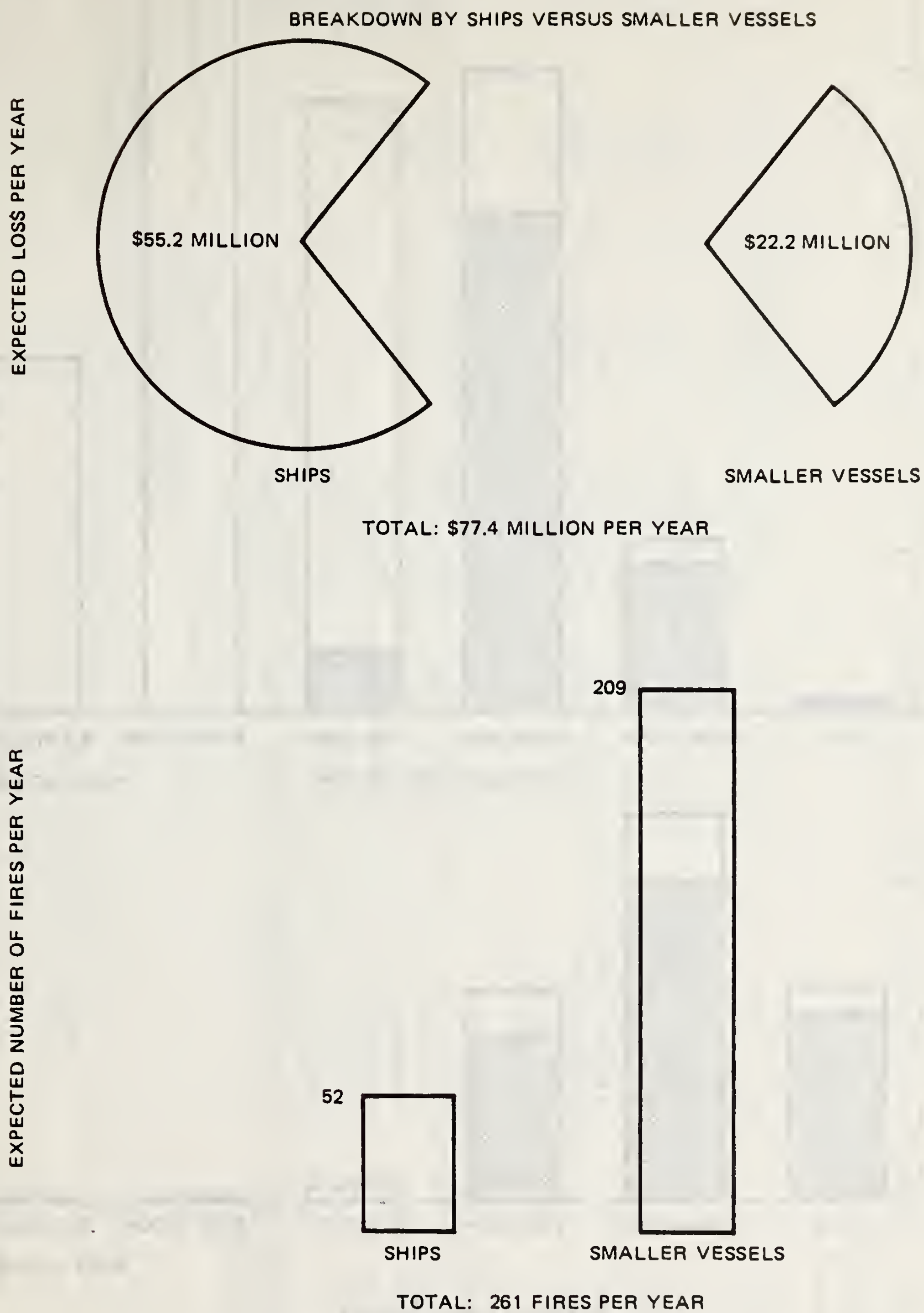


FIGURE II–4 MARINE FIRE LOSSES, STATUS QUO, 1980–2000

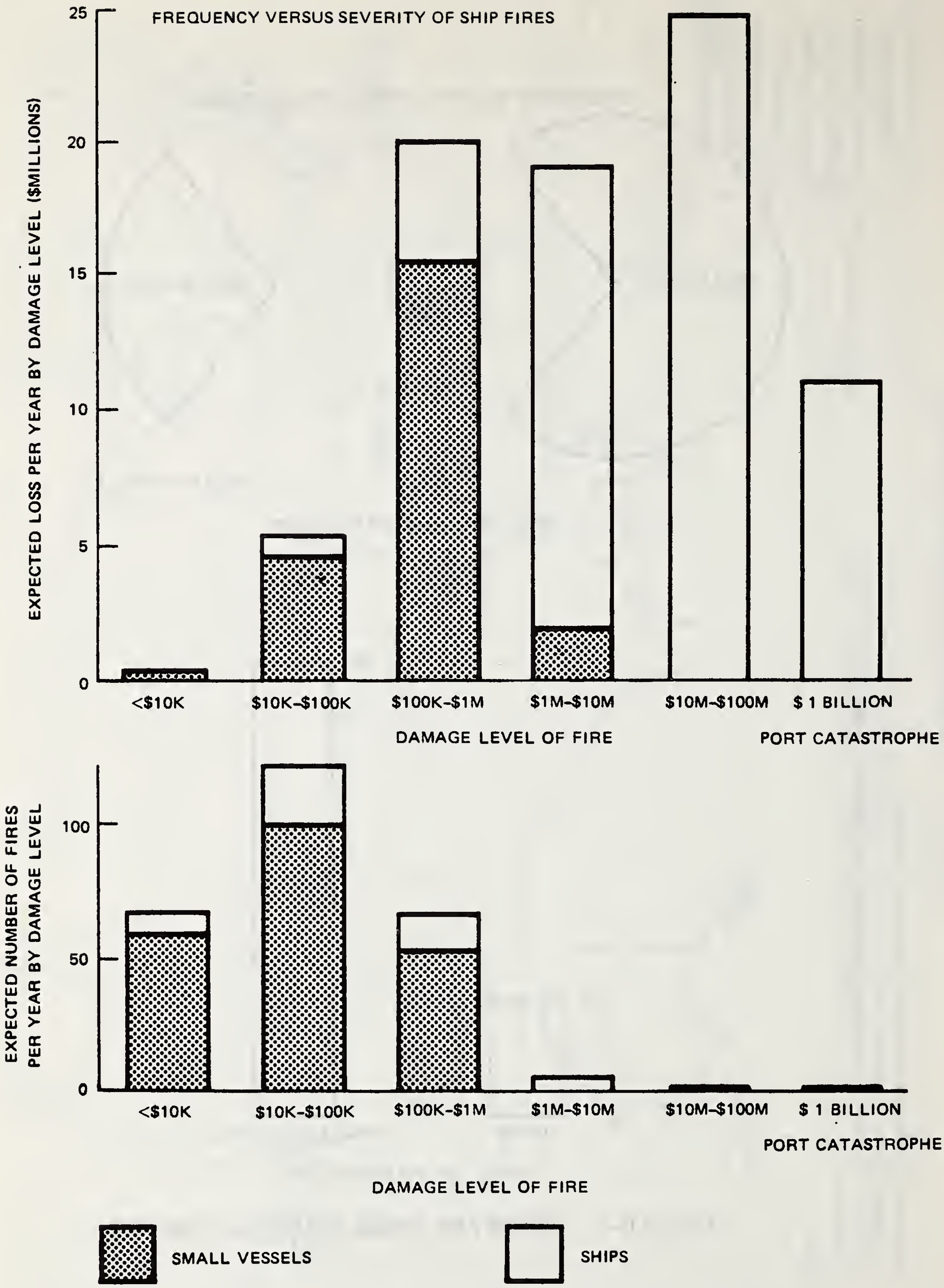


FIGURE II-5 MARINE FIRE LOSSES, STATUS QUO, 1980-2000

Table II-3

MARINE FIRE LOSSES, STATUS QUO, 1980-2000, BY SHIP TYPE

Expected Number of Fires per Year	Type of Vessel	Average Loss per Year (millions of dollars): Vessel	Cargo	Human Death/Injury	Waterfront and Commercial	Port Catastrophe	Total
	Ships*						
32.1	Freighter	12.6	3.4	8.4† 2.8 13.4	1.1	2.9	22.8
7.8	Container	5.2	3.6	1.9 0.6 3.2	0.2	0.4	10.0
10.1	Tanker	8.8	1.0	6.1 2.0 4.4	2.5	7.5‡	21.8
1.7	Passenger	0.2	0.1	0.6 0.2 1.0	0.1	0.0	0.6
51.7	All ships	26.8	8.1	17.0 5.6 22.0	3.9	10.8	55.2
	Small vessels						
15	Tank barge	1.9	0.3	2.9 1.0 6.3	2.0	0.0	5.2
14	Cargo barge	0.3	0.3	1.2 0.5 2.8	0.0	0.0	1.1
80	Fishing boat	4.0	0.0	4.6 1.6 8.8	0.0	0.0	5.6
60	Tug, tow, utility	5.6	0.0	5.6 1.9 7.9	0.0	0.0	7.5
40	Miscellaneous	2.6	0.0	0.2 0.2 4.2	0.0	0.0	2.8
209	All small vessels	14.4	0.6	14.5 5.2 30.0	2.0	0.0	22.2
260.7	All vessels	41.2	8.7	31.5 10.8 52.0	5.9	10.8	77.4

*Categories as defined in text.

†The small numerals are the number of deaths and injuries.

‡Includes $2.5 million for LNG port catastrophe; see Chapter IX, The LNG Port Catastrophe.

Table II-4

MARINE FIRE LOSSES, STATUS QUO, 1980-2000,
BY SHIP LOCATION, FIRE LOCATION, AND FIRE DEVELOPMENT
(Ships Only)

Breakdown by Ship Location

Expected Number of Fires per Year	Ship Location	Average Loss per Year (millions of dollars) All Categories	Average Loss per Year (millions of dollars) Excluding Port Catastrophe
25.8	At dock	31.9	22.0
6.6	In harbor or near land	14.1	13.2
19.3	At sea	9.2	9.2
51.7	All ship locations	55.2	44.4

Breakdown by Fire Location

Expected Number of Fires per Year	Fire Location	Average Loss per Year (millions of dollars) All Categories	Average Loss per Year (millions of dollars) Excluding Port Catastrophe
25.9	Engine room	19.7	18.0
15.5	Cargo hold (dry cargo vessels)	11.9	9.8
2.5	Cargo tank (tankers, includes LNG)	15.0	8.3
7.8	Superstructure	8.6	8.3
51.7	All fire locations	55.2	44.4

Breakdown by Fire Development

Expected Number of Fires per Year	Fire Development	Average Loss per Year (millions of dollars) All Categories	Average Loss per Year (millions of dollars) Excluding Port Catastrophe
0.2	Tanker cargo explosions	4.9	2.7
7.4	Engine room explosions	8.9	8.2
1.1	Collisions resulting in fire	10.9	9.6
43.0	All others	30.5	23.9
51.7	All fire developments	55.2	44.4

dock and a slight increase in the corresponding percentage at sea. The breakdown by fire location shows the huge reduction in losses in cargo tank fires, primarily resulting from the tanker inerting program (discussed at the end of this chapter); cargo tank fires are reduced from 9% of fires and 45% of losses in the status quo, 1975 to 5% of fires and 27% of losses in the status quo, 1980-2000. As a result, engine room fires are expected to cause more losses than any other single class of fires. The third breakdown, by fire development, again shows the impact of tanker inerting. The expected number of cargo tank explosions is reduced from 1.0 to 0.2 per year, but when they occur they still cause a large loss, making up 9% of the total. Collisions resulting in fire (always involving tank vessels) still occur every 1.8 years and cause 20% of the losses.

This status quo for 1980-2000, with an average annual loss of $77.4 million, is the background or base case against which all the marine fire protection programs we propose in Chapter III are compared.

How the Status Quo, 1975 Marine Fire Losses Were Measured

The first step in analyzing the status quo was determining the magnitude of marine fire losses over the past several years. As a starting point, we obtained 14 years of U.S. Coast Guard records of fires, explosions, and collisions resulting in fire, for all ships included in the scope of this study (all merchant vessels in U.S. ports and waters and U.S. flag merchant vessels at sea and in foreign ports and waters). These records provide, for each ship fire, an account of the fire, a description of the extent of damage, and an estimate of the monetary loss. The fire accounts and the damage descriptions are accurate, but there is a general consensus, even within the Coast Guard, that the estimates of monetary loss are inaccurate and incomplete. This shortcoming of the loss data stems from three basic reasons (1) the Coast Guard's primary responsibility is determining the cause of the fire rather than the loss (so that safety precautions may be taken in the future) (2) neither the Coast Guard nor local fire departments have access to all the information required to measure monetary losses, particularly when the estimates are made shortly after the fire and (3) there are components of loss such as unemployment and the disruption of commerce that the Coast Guard does not attempt to estimate.

To obtain an accurate estimate of marine fire losses, we used the Coast Guard records to identify the details of each ship fire, but we used the records of insurance companies, salvage associations, shipping lines, naval architects, and marine surveyors to determine actual monetary losses. Unfortunately, actual monetary losses were available from these sources for only some of the fires. This more reliable data was used as a basis for estimating losses in the other fires. We believe this process provides better estimates of losses in these fires than the estimates provided by the Coast Guard.

This method for estimating losses is simple in principle: Coast Guard data are used to determine the frequency of the different types of ship fires and the level of damage in each case, and insurance company, salvage association, and shipping line data are used to estimate the monetary losses associated with each level of damage. Figure II-6 shows the data requirements for this estimating procedure. The data needed were: (a) the average number of fires per year, (b) a breakdown by type of ship fire (which we call the fire scenario), (c) the percentages of different damage levels in each type of ship fire, and (d) the equivalent dollar loss for each of these cases.

The Coast Guard records provided the information needed to compute data items (a), (b), and (c). From 14 years of records, we determined the average number of fires per year and identified for each fire the type of ship involved, its size, age, location at the time of the fire, the location of the fire aboard the ship, and the manner in which the fire developed. We then used this information to determine the probability associated with each branch of the fire scenario section of the tree in Figure II-6. The full set of fire scenario probabilities and the method by which they were derived are presented in Chapter VI, The Fire Scenario Model.

We also used the Coast Guard records to determine the physical extent of damage in each fire. Because damages in ship fires can vary greatly, we had to develop a consistent framework for specifying damages. To provide such a framework, we engaged numerous marine experts, including naval architects, marine surveyors, marine firefighters, and fire protection engineers. Together with them, we constructed a "fire involvement and damage model" that defines six discrete levels of fire involvement and resulting damage that span the full range of fire and damage possible in ship fires. These six levels, labeled Level 1 through Level 6 in Figure II-6, range from a mattress fire in one seaman's living compartment (a Level 1 superstructure fire) to the total destruction of the ship and its cargo (a Level 5 fire). The highest level of damage (Level 6) is modeled after the Texas City port catastrophe of 1947 in which not only were the ship and cargo destroyed, but the entire waterfront district was damaged or destroyed and hundreds of lives were lost. The Levels 2, 3, and 4 fires describe damages of increasing severity between the minor fire and the total loss. Each of the six levels of damage describes, for each type of fire, the damage done to the vessel, cargo, humans, the waterfront, and general commerce. The full set of fire involvement and damage profiles is listed in Tables VII-1, VII-2, and VII-3 of Chapter VII, and described in more detail in Chapter VIII.

Equipped with this framework for classifying damages, we used the Coast Guard records from 1963-76 to determine the extent of damage (Level 1, 2, 3, 4, 5, or 6) in each ship fire. This information enabled us to answer the following type of question: Of all engine room fires aboard tankers, what percentage resulted in each of the six damage levels? This percentage distribution was determined for each ship type

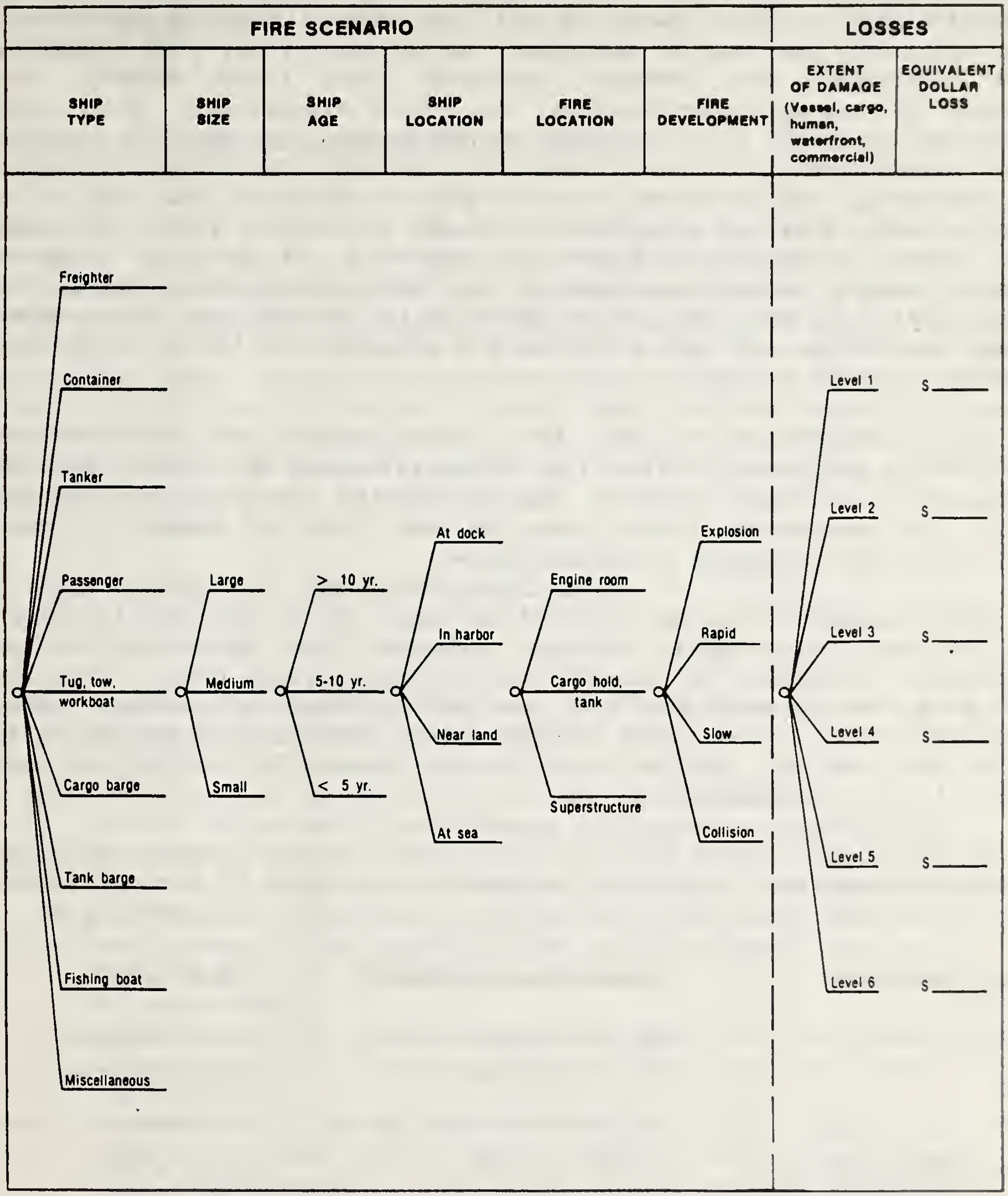


FIGURE II-6 MEASURING MARINE FIRE LOSSES, STATUS QUO, 1975

and fire location; the full set of these distributions is presented in Figure IX-7.

The only remaining information needed for the tree in Figure II-6 was the monetary loss associated with each level of damage for each type of fire. Converting damage levels to equivalent dollar losses is a difficult procedure. To perform this task, we consulted with numerous marine industry experts including hull and cargo insurance personnel, naval architects and marine engineers, marine surveyors, port authority trade specialists and terminal managers, Coast Guard experts, and shipping line marine superintendents and repair supervisors. With their assistance, we built five separate "value" models, one each for vessel, cargo, human, waterfront and commercial, and port catastrophe damages. The methodology and data for each of these models are too complex to describe here; they are described in depth in Chapter VIII, The Value Model. Here, we mention only that the estimates for each loss category for each level of damage are based on the best information available and are calibrated to reproduce actual known dollar losses in a large number of past incidents. All dollar losses are adjusted for inflation and are expressed in 1975 dollars.

It is important to note that human deaths and injuries are converted to equivalent dollar loss figures because all losses must be expressed in the same units for decision-making purposes (see Chapter VIII). The equivalent dollar loss for each level of damage for each type of fire is presented in Figure VIII-1.

Having gathered all the information required for the tree in Figure II-6, we used the weighted average technique, just as we did in the introductory tutorial, to compute the average annual loss. The only difference here is that the tree now has thousands of possible paths rather than just the two paths of Figure I-3. The figures and tables in the earlier section, "Marine Fire Losses, Status Quo, 1975," are the result of this computation.

We mentioned earlier that the Coast Guard records provide estimates of monetary damages. Below, we compare our estimates of average annual loss for merchant ships with the corresponding Coast Guard estimates.

Loss Categories	Coast Guard Estimate	SRI Estimate
Vessel	$12.9 million	$24.6 million
Cargo	$ 3.6 million	$ 5.6 million
Human	20 deaths, 19 injuries	20 deaths, 19 injuries
Waterfront/Commercial	$ 1.8 million	$ 5.7 million
Port catastrophe	___	$13.2 million

The differences stem from the shortcomings of the Coast Guard loss data discussed at the beginning of this chapter plus the fact that the Texas

City fire of 1947 was not included in the 14 years of Coast Guard records that were available. The death and injury losses are in complete agreement, because we built our model to reproduce these Coast Guard statistics that we believe are accurate. For the smaller vessels, our estimate for all loss categories is exactly the same as the Coast Guard estimate; we were advised by marine surveyors that valuation of damage of small vessels is a far simpler task than for large vessels and that the Coast Guard records for these vessels should be reasonably accurate.

Profile of the Marine Fire Protection System

The key aspects of the current marine fire protection system should be kept in mind to understand the status quo and all the alternatives we propose in Chapter III. A brief perspective is given below naming the organizations that play an important role in marine fire protection and listing their relevant responsibilities. The brief perspective also includes a list of the types of fire protection equipment currently found aboard ships. More detailed descriptions of these elements of the current marine fire protection system are included where relevant throughout this report. Appendix A of the report includes a brief perspective of the key aspects of the maritime industry that affect the marine fire situation.

Organizations and Their Responsibilities

U.S. Coast Guard

- Regulation regarding shipboard firefighting equipment and vessel materials and construction.
- Inspection of vessels.
- Licensing and certification of merchant seamen.
- Control of movement and stowage of hazardous materials in port areas.
- Control of movement of vessels in harbors and congested waterways.
- Development of contingency plans in conjunction with local fire departments for marine disasters, including mutual aid agreements.
- Participation in international agreements on ship safety through IMCO, the Intergovernmental Maritime Consultative Organization.
- Assistance in fighting marine fires; in this regard, the Coast Guard has left primary responsiblity to municipal fire departments. The Coast Guard assumes primary responsibility either where the fire department has no marine manpower and equipment or in waters beyond municipal fire department jurisdiction.

- Research and testing in fire prevention, detection, and suppression.
- Investigation of marine casualties and accidents and record-keeping.

Municipal and Port Authority Fire Departments and Private Fire Brigades

- Suppression of ship and waterfront fires in their jurisdictions.
- Disaster planning in conjunction with Coast Guard.
- Training: These professional firefighters are already well trained in fighting structural and flammable liquid fires. With regard to the special characteristics of ship fires, their training falls into three broad categories:
  - Having expertise in marine firefighting.
  - Having some familiarity with the layout of ships and some awareness of special dangers.
  - Having no familiarity with ships.
- Equipment: Fireboats are present in most major port cities. High pumping capacity fireboats currently are present in U.S. port cities handling 61% (by tonnage) of foreign and domestic trade; the port cities handling the remaining 39% of the tonnage do not have high pumping capacity fireboat protection. In some of these smaller ports, the Coast Guard provides fireboats with low pumping capacity. Other fire department marine firefighting equipment includes land vehicles, portable pumps, and access to large quantities of CO_2, foam, and other agents.

Port Authorities and Port Commissions

- Regulation of cargo and terminal operations.
- Suppression of fires by specially trained fire squads.

Maritime Academies and Firefighting Schools (federal, state, and private)

- Training in fire prevention and suppression for officers and seamen; this training provides basic knowledge and psychological preparedness, but not proficiency in firefighting.

Maritime Administration

- o Training in fire prevention and suppression for merchant marine officers and crews.
- o Incorporation of fire protection equipment in ship designs.
- o Location of ports and terminals.
- o Research in communication and safety procedures.

National Fire Protection and Control Administration

- o Development of training programs for fire departments.

Shipowners, Naval Architects, Shipbuilders, and Ship Operators

- o Selection of shipboard fire detection and suppression equipment.
- o Influence on level of fire consciousness and preparedness of crew.

Maritime Unions

- o Training in firefighting provided for members, but not compulsory.

Fire Protection Industry

- o Design and manufacture determining reliability of equipment and ease of use.

American Bureau of Shipping and the Marine Insurance Industry

- o Inspections of ships for insurance rating.
- o Setting of premiums which may influence shipowners' attitudes toward fire protection.

<u>Shipboard Fire Protection Equipment</u>

- o Fire detection and location systems.
- o Fire resistant bulkheads and fire doors.
- o Portable extinguishers.
- o Fire pumps and hand lines, with emergency power supply.
- o Volume flooding CO_2 or halon systems in engine and cargo spaces.

- Foam systems on tankers.
- Eductor pumps.
- Lifeboats.
- Each ship has a fire bill and a simple plan displaying the layout of all fire protection equipment.

Relating Status Quo, 1975 Losses to the Performance of Status Quo, 1975 Marine Fire Protection System

To estimate the effects of new trends and programs on future marine fire losses, we first had to relate losses to the performance of the current marine fire protection system. To develop this relationship, we had to build the entire probability tree, shown in Figure I-1, for the Status Quo, 1975.

To relate status quo losses to status quo firefighting performance, the first step in this task, we had to trace the growth of each fire from its size when the firefighters arrived to its maximum involvement and the ultimate extent of damage. This process is analogous to Step 2 of the introductory tutorial, but far more complicated. It is by far the most difficult and most time-consuming part of the analysis. With the completion of this task, the model becomes a tool for measuring the effectiveness of the current marine fire protection system and for analyzing the impact that can be expected from making changes in the system. In this chapter, we present only a brief description of this model of firefighting performance. The complete methodology and data are presented in Chapter IX, The Firefighting Performance Model.

Figure I-1 shows the firefighting performance section of the decision tree. It is divided into two parts: initial response and fire suppression. The initial response describes the crew response in each type of fire and its effect on the size of the fire when the organized firefighting force arrived. To determine the probability of a good or bad crew response and the probability of the initial fire level, we reviewed numerous marine casualty reports and interviewed numerous marine firefighting experts in fire departments, firefighting schools, shipping lines, and port authorities. These probabilities vary for each fire scenario; they are presented in Figure IX-1 in Chapter IX.

The fire suppression segment of the tree shows the different possible teams of firefighters that would fight a ship fire whether at dock, in harbor, near land, or at sea. The first set of branches describes the different possible levels of expertise that may characterize the officer in command of the firefighting forces; the second set of branches describes different possible levels of training of the firefighters themselves. It is important to realize that all of these levels of expertise and training currently exist to some degree on various ships and in various port cities around the country.

We contacted numerous shipping lines, firefighting schools, and maritime unions, and conducted a survey of 30 port city fire departments (listed in Chapter IX) to ascertain the existing levels of marine firefighting expertise and training. This survey provided the probabilities for the fire suppression branches of the tree; these probabilities are presented in Figure IX-3. The land-based figures are the weighted averages* of the probabilities that in each port city the firefighters who respond to a ship fire have the various combinations of marine firefighting expertise and training. These figures, therefore, represent the average effective level of expertise and training in marine firefighting currently found in port city fire departments all over the country. When interpreting a nationwide average, one must remember that some fire departments may be far above the average and others may be far below. The average level of marine firefighting expertise and training for ship-based forces is presented in Figure IX-3. The details of accounting for foreign and domestic crews are described in Chapter IX.

The information described thus far enabled us to answer the following questions for each fire: What type of fire was it? How extensive was the fire when the firefighters arrived? What was the level of expertise and training of the officers and firefighters? The key question remaining to be answered was: How extensive was the damage when the fire was extinguished? To answer this question, we interviewed numerous marine firefighting experts in fire departments, firefighting schools, shipping lines, and port authorities in port cities all around the country.

Following the individual interviews, we convened a marine firefighting forum at SRI International headquarters in May, 1978 with a few selected experts. At this forum, a consensus was reached on the effect of the different firefighting teams, prefire plans, tactics, and pieces of equipment in each of the fire scenarios. Firefighting effectiveness was quantified in terms of the probability that a given firefighting team arriving at a fire of a given level (Level 1, 2, 3, 4, or 5) could extinguish the fire at that level, as opposed to having it grow to the next higher level. The probabilities describing the growth of the fire from one level to the next depend strongly on the ability of the fire officer to deploy the built-in suppression system, if available. The correct deployment of the built-in system makes such a large difference in the effectiveness of the firefighting effort that we include it as a separate element in the decision tree. These measures of firefighting effectiveness and the procedure for assessing them are presented in Chapter IX, The Firefighting Performance Model, Transition from Initial Level of Fire Involvement to Final Level of Damage. The names of the marine firefighting experts we interviewed and of the five

---

* The weighting factors are the individual port percentages of total U.S. foreign and domestic maritime shipping tonnage.

who participated in the forum at SRI are also included in that section of Chapter IX.

The forum provided us with the final set of expert judgments needed to relate current losses to the current fire protection system. The only task remaining was to use these quantitative judgments to link the fire scenario and the final damage levels so that the model would reproduce the status quo fire and loss statistics. As can be expected, some calibration of the model was needed to filter out any serious biases reflected in the experts' judgments. One of the key advantages of this methodology is that it uses the experts' judgments of firefighting effectiveness to relate known historical losses to known historical fires. If there is any strong systematic bias in the judgments, a proper matching of losses to fires cannot be achieved. The method used to calibrate the model and validate it against the historical data is described in Chapter IX, The Firefighting Performance Model.

Having validated the model on the basis of the status quo, 1975 historical data, we then used it to estimate the increase or reduction in fire losses that could be expected from changes in the marine fire protection system or in the maritime industry.

How the Status Quo, 1980-2000 Marine Fire Losses Were Estimated

As demonstrated in the tutorial example in Chapter I, a model built on the basis of fires in the past is an adequate tool for estimating the impact of programs in the future only if the pattern of ship fires and losses in the future is expected to mirror the experience of the past. Needless to say, several new developments in the maritime industry and in the marine fire protection system will change the number and type of ship fires in the future, the effectiveness of the firefighters, and the amount of damage. The pilot program in Puget Sound and the bill before Congress proposing that it be adopted nationwide have perhaps served as catalysts motivating other agencies to develop fire protection programs of their own. Whatever the reason, new developments are now taking place which will affect the future marine fire situation independently of whether any of the alternatives we are considering in this study are adopted. As such, these new developments must be incorporated in the model so that they become part of the "status quo" or base case for the years 1980-2000.

These new developments are listed below as either new trends in the maritime industry or new programs in marine fire protection.

New Trends in the Maritime Industry

(1) The number of U.S. flag and foreign flag vessels engaged in U.S. trade will increase during the years 1980-2000.

(2) The size of vessels engaged in U.S. trade will increase during the years 1980-2000.

(3) Liquified natural gas (LNG) shipping will increase in U.S. ports in the period 1980-2000.

New Programs in Marine Fire Protection

(1) A recent agreement of the Intergovernmental Maritime Consultative Organization (IMCO) will require that almost all tankers of more than 20,000 deadweight tons (Dwt.) that are engaged in international trade must have inert gas systems protecting their cargo tanks from explosions. Specifically, all new crude oil carriers of 20,000 Dwt. or greater and all new product carriers of 20,000 Dwt. or greater will have to be equipped with tank inerting systems when constructed. Existing crude oil carriers of greater than 70,000 Dwt. will have to be inerted by 1981, and existing crude oil carriers of 20,000-70,000 Dwt. will have to be inerted by 1983. Carriers of less than 20,000 Dwt. are exempted from these inerting requirements. Even in the absence of an international agreement, the U.S. Coast Guard will enforce these same standards for all U.S. flag tankers and all tankers entering U.S. ports and waters. The net result is that almost all tankers over 20,000 Dwt. included in this study will be inerted.

(2) Vessel traffic control systems, operated by the U.S. Coast Guard, have recently been put into operation in a few major ports and one additional system is planned by 1980 for the port of New York. These systems reduce the number of collisions in the areas they cover, and consequently reduce the number of fires caused by collisions.

(3) A recent IMCO agreement will require a tankerman rating for various personnel aboard all tankships involved in international trade. The tankerman rating includes training in fire protection and firefighting. A U.S. Coast Guard regulation expected to be adopted in a few months will require this same tankerman rating on all tankships and tank barges involved in U.S. trade. As a result, the tankerman rating applies to all tankers and tank barges included in the scope of this study.

(4) Another IMCO agreement, which Maritime Administration sources advise us will be adopted by 1982, will require firefighting training for the majority of merchant seamen on all oceangoing vessels. This mandatory firefighting training will apply to all deck and engineering officers, all navigational and engine room watch-standers, and all radio operators. When the agreement is ratified, the U.S. Coast Guard will extend the regulation to include the same

personnel on all merchant ships in U.S. domestic trade. Consequently, seamen aboard all merchant ships included in this study, regardless of the type of cargo, will have firefighting training.

The Maritime Administration is setting up four new facilities, one each on the Atlantic Coast, the Gulf Coast, the Great Lakes, and the Pacific Coast, to provide the firefighting training for merchant seamen mandated by these new agreements and regulations.

In Part Two of this report, we present a quantitative explanation of how each of these new trends or programs affects the Fire Scenario, Firefighting Performance, and Value Models. In this chapter, we explain briefly how each trend or program affects ship fires and we provide estimates of the resulting increase or reduction in marine fire losses.

If we assume that the number of ship fires is proportional to the number of ships, the increase predicted in the number of ships engaged in U.S. trade in 1980-2000 will result in more ship fires per year. Also, the increase in size of vessels will make the total loss of a ship more costly. By incorporating these new trends in the model (described in detail in Chapters VI and VIII), we estimate that the annual average loss would increase from $74.6 million in the past to $97.0 million in the future. Adding an expected $2.5 million annual contribution from the LNG port catastrophe (see Chapter IX), we estimate average annual marine fire losses for the period 1980-2000, under the status quo alternative, would grow to $99.5 million. These losses by category are:

<u>Ships</u>

<u>Loss Categories</u>	<u>Millions of Dollars</u>
Vessel	36.1
Cargo	11.1
Human	8.0 (24.6 deaths, 27.2 injuries)
Waterfront/Commercial	5.9
Port catastrophe	+ 16.0
	77.1

Smaller Vessels

Loss Categories	Millions of Dollars	
Vessel	14.5	
Cargo	0.6	
Human	5.2	(14.5 deaths, 30.0 injuries)
Waterfront/Commercial	2.1	
Port catastrophe	+ 0.0	
	22.4	

The new programs in marine fire protection that are now or will soon be implemented under the status quo alternative, however, will eliminate some losses. The tanker inerting program will cause a drastic reduction in tanker explosions which, as shown in Table II-2, were among the worst type of ship fires. Tanker explosions will still be possible, because (1) small tankers are exempted from the inerting regulations, (2) the inerting systems are not 100% reliable, and (3) the inerting systems are not used when drydock repairs are being made. By incorporating the tanker inerting program in the model (as described in Chapter VI), we estimate a $13.7 million average annual reduction in marine fire losses. This $13.7 million is the sum of savings of $4.3 million in vessel damage, $1.0 million in cargo damage, $1.5 million in human damage (4.7 deaths and 2.1 injuries), $1.9 million in waterfront and commercial damages, and $5.0 million in port catastrophe damage.

The U.S. Coast Guard vessel traffic control systems, by reducing the likelihood of collisions, reduce the likelihood of some of the worst ship fires. By determining the percentage of collisions that have occurred in the port areas where vessel traffic control systems will operate, and by predicting the percentage reduction in collisions resulting from these systems (see Chapter VI, The Fire Scenario Model, Status Quo, 1980-2000), we estimate a $1.5 million average annual reduction in marine fire losses. This is the sum of savings of $0.7 million in vessel damage, $0.3 million in cargo damage, $0.2 million in human damage (0.6 deaths and 0.6 injuries), $0.1 million in waterfront and commercial damage, and $0.2 million in port catastrophe damage.

The third new fire protection program, the tankerman rating, has a smaller impact than some may expect because personnel involved in loading and unloading flammable liquids already have this rating on a large percentage of tank vessels (see Chapter IX). By incorporating the tankerman rating requirement in the model, we estimate that it results in a $1.8 million average annual reduction in marine fire losses. This is the sum of savings of $0.9 million in vessel damage, $0.1 million in cargo damage, $0.2 in human damage (0.7 deaths and 0.4 injuries), $0.2 million in waterfront and commercial damage, and $0.4 million in port catastrophe damage.

Finally, the regulations coming in the near future for mandatory firefighting training for the majority of merchant seamen (aboard all merchant ships included in the scope of this study) will improve their effectiveness (see Chapter IX). By incorporating these changes in the model, we estimate a $6.1 million average annual reduction in marine fire losses. This is the sum of savings of $3.7 million in vessel damage, $1.7 million in cargo damage, and $0.7 million in human damage (2.1 deaths and 2.6 injuries). The reduction in waterfront, commercial, and port catastrophe damages from this program is negligible.

In summary, the new trends in shipping would increase average marine fire losses from $74.6 million to $99.5 million per year, but the new marine fire protection programs under way are estimated to reduce this future loss by the following amounts:

Program	Expected Reduction in Loss (millions of dollars)
Tanker inerting	13.7
Vessel traffic control	1.5
Tankerman rating	1.8
Mandatory fire training	6.1

Each of the four numbers in this list represents the expected reduction in loss from that program alone. Adding these four numbers does not give the reduction in loss from all four programs taken together because some of the savings overlap. For example, the tanker inerting prevents some of the fires in which the tankerman rating program makes its savings. When all four programs are incorporated simultaneously in the model, and care is taken to eliminate any double counting, we find that the average annual reduction in marine fire losses from these four programs taken together is $22.1 million. The average marine fire losses for the status quo, 1980-2000 are expected to be $77.4 million per year, determined by subtracting the $22.1 million from the $99.5 million figure.

It is interesting to note that the new marine fire protection programs decrease losses by just about as much as the new trends in shipping increase losses. The average status quo, 1975 losses were $74.6 million per year; the corresponding figure for the status quo, 1980-2000, taking into account the new trends and programs, is $77.4 million. However, the composition of these losses is expected to change considerably.

III ALTERNATIVE MARINE FIRE PROTECTION PROGRAMS

The previous chapter described current marine fire losses and those expected in the years 1980-2000. In this chapter, we develop a list of alternative marine fire protection programs that could be implemented on a nationwide scale and that could substantially reduce these losses. We emphasize alternatives that would improve fire protection for ships because, as shown in the previous chapter, the bulk of the losses occur in ship fires rather than in smaller vessel fires.

Several criteria were used to select a manageable number of alternatives out of the thousands that are possible. First, all alternatives had to be broad-based plans having substantial impact on the national marine fire problem. Second, minor or regional variations on alternatives were not to be considered; these variations would not substantially change the cost-effectiveness of the plan and would be considered at the time of implementation. Third, only alternatives that would improve the level of marine fire protection in the years 1980-2000 were considered; programs aimed only at reducing the cost of current levels of protection were not within the scope of this study.

The programs described below consider, in turn, improvements in the marine firefighting ability of land-based firefighting forces, improvements in the firefighting ability of ship crews, improvements in firefighting equipment aboard ships, and improvements in fire prevention measures. A number of other programs are considered briefly at the end of the chapter; preliminary analysis showed that they are not sufficiently cost-effective to warrant detailed analysis.

The discussion below is intended only to identify the programs. Chapter X provides a complete discussion of the structure of each program, its cost, and the specific way in which it improves the marine fire protection system.

Maintain Status Quo: One of the obvious alternatives is to maintain the status quo marine fire protection system. As noted in Chapter II, the status quo is not static, but is changing because of new trends in shipping and new fire protection programs currently being or soon to be put into effect.

The status quo, 1980-2000 is the base case against which all other alternatives are compared. None of the programs we consider involve any diminution of the current marine fire protection system; the alternatives we consider only add to the system.

Seattle Plan: This alternative is the nationwide implementation of the pilot program conducted in the Puget Sound area, as proposed to

Congress in H.R. 11459. The essence of the plan is land-based marine firefighting expertise provided by regional teams; each team has a small number of specialists in marine firefighting who cover as large an area as possible. Teams of five professional firefighters specially trained in fighting ship fires are placed in key port areas of the United States; the team members remain within the municipal fire departments, but spend full time in activities related to marine fire protection. The main functions of these teams are

- To give aid and advice to anyone within their area who is engaged in fighting a ship fire; if the occasion warrants, they can take part in the actual firefighting.
- To prepare detailed prefire plans of ships that regularly call at U.S. ports. Because of these prefire plans, firefighting advice can be given by radio to ships at sea. If the ship is close enough to land, the team and special equipment can be transported to the ship by helicopter.
- To provide low level training in marine firefighting to municipal fire departments in their regions. Such training would include basic familiarity with ship layout, nautical terminology, and special precautions in marine firefighting.

Each team maintains a cache of equipment specifically gathered for fighting ship fires. In addition, easily portable, high-capacity turbine pumps are kept at the five regional headquarters to be available for fighting major ship fires.

The proposed legislation also includes a provision for the regional teams to train merchant seamen in firefighting. Our analysis shows, however, that the regional teams would have neither the facilities nor the time to train any significant number of seamen in hands-on firefighting.

H.R. 11459 also includes a provision for a national data center for ship fires. In Chapter II and Appendix D of this report, we comment on the adequacy of the Coast Guard records and improvements that could be made to provide the informational needs required.

The exact number of regional teams is not specified in the legislation that has been introduced before Congress. Our model, however, is capable of estimating the net savings that can be expected from locating a team in any specific port area; we have therefore been able to optimize the design of the Seattle plan by determining in which port areas the teams would be cost-effective. The optimized Seattle plan consists of teams in the 24 ports shown in Figure III-1; the circles around each port area indicate the 50-mile radius within which the teams can furnish effective marine fire protection. Two more ports, Wilmington, NC and Charleston, SC, were at the break-even point, but could easily be included in the program; an Alaskan port, Anchorage or

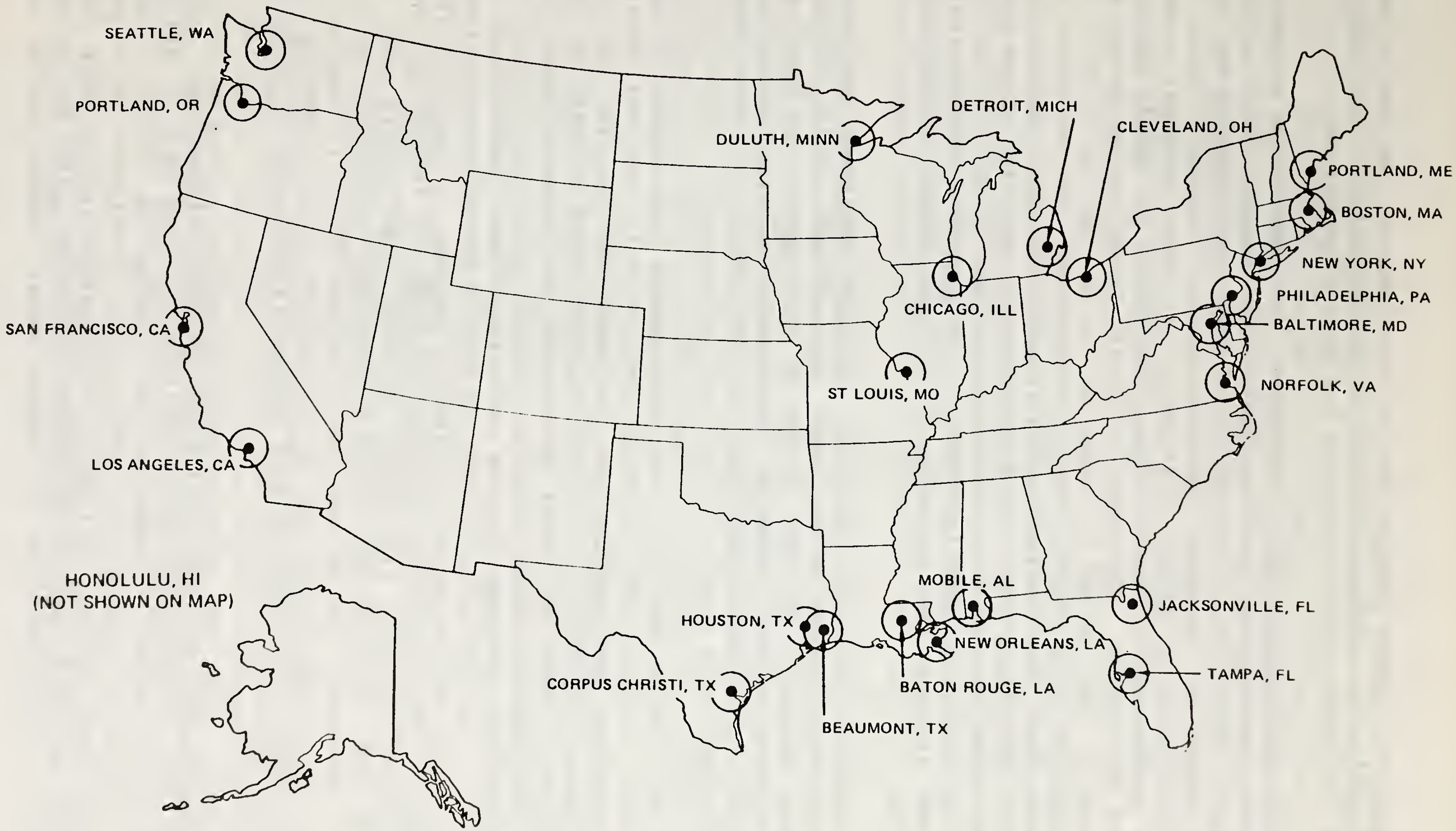


FIGURE III-1 CITIES IN WHICH TEAMS WOULD BE PLACED IN THE OPTIMAL FORM OF THE SEATTLE PLAN

Valdez, will be in this category in the near future. The cost of the optimized program is estimated to be $4.98 million per year (see Chapter X for the cost computation of this and the other alternatives).

Fire Chief Expertise Plan: Experienced firefighters have suggested that a more decentralized plan could have much the same effect as the Seattle plan. Specifically, the Fire Chief Expertise plan proposes that battalion chiefs of municipal fire departments be given 3 weeks of specialized training in marine firefighting, followed by annual 1-week refresher courses; after this training, they return to regular duty in their fire departments. The number of chiefs to be trained should be large enough so that, during all three shifts, at least one chief is on duty in the port area of his city. The majority of fire chiefs we interviewed felt that battalion chiefs were the most appropriate officers for this assignment. In each port city, the chief of the fire department should have the discretion to select the officers to participate in this program (whether they be chiefs or captains) and should vest in them the authority to act as advisors in any ship firefighting effort.

To increase the effectiveness of the plan, equipment and pumps identical to those of the Seattle teams are made available to the fire departments in each of the port cities in the program. In addition, simple prefire plans, prepared from available ship plans, are distributed to the fire departments of port cities at which ships customarily call.

Our model shows that this plan would reduce fire losses by more than it would increase fire protection costs, even in very small ports. To provide a basis for comparing the Fire Chief Expertise plan with the Seattle plan, we define it to cover all port areas affected by the Seattle plan. These port areas include the 24 cities in which the Seattle plan regional teams would be located, all ports within the 50-mile effective striking distance covered by these teams (shown in Figure III-1), and port cities beyond the 50-mile radius where the teams would provide in-service marine firefighting training for municipal fire departments. This area of coverage includes 68 individual port municipalities. In the Fire Chief Expertise plan, chiefs must be trained in each of the 68 port cities because each municipality has its own fire department; the 68 municipalities are listed in Chapter X. These 68 port cities handle 94% of all tonnage in U.S. domestic and foreign shipping. The cost of this program is estimated to be $2.04 million per year.

Fire Department Low Level Marine Firefighting Training Plan: The two previous alternatives give specialized knowledge in marine firefighting to those in command of the firefighting effort; a more modest alternative would provide professional firefighters with some familiarity with ships. Officers and firefighters in many fire departments in port cities are unfamiliar with ships. They do not know the general configurations of engine rooms, cargo holds, and

superstructures, nor do they know how to gain access to these spaces. In addition, they are not familiar with nautical terminology, making effective communication with the ship's crew very difficult. To remedy this situation, the Low Level Firefighting Training plan proposes a course of action that has already been tried in several port cities: as part of their in-service training, personnel in stations most likely to respond to ship fires are given 40 hours of training each year. This training acquaints the men with ships, nautical terminology, and the special dangers associated with fighting ship fires. This training consists mostly of inspections of ships, supplemented by some audiovisual instruction.

Because this low level training is in-service training, it is inexpensive. Our model shows that the program would reduce fire losses by more than it would increase fire protection costs, even in very small ports. We propose this program in the same 68 port cities as in the Fire Chief Expertise plan; these 68 cities correspond to the same geographic coverage provided by the 24-team Seattle plan. The cost of this program is estimated to be $0.32 million per year.

Coast Guard Reserve Plan: The previous three alternatives have involved marine firefighting expertise or training for members of municipal fire departments. The fourth program we consider would supply marine firefighting expertise to municipal fire departments through advisors in Coast Guard Reserve units composed of professional firefighters. A program of this type is already being tried in the Los Angeles-Long Beach area. The program we analyze on a nationwide basis would operate in the following way:

- Teams of 15 professional firefighters would be formed in the Coast Guard Reserve, which already has about 300 firemen billets that could be filled with professional firefighters. These firefighters would be trained in marine fire protection as part of their duty in the Coast Guard Reserve.
- These teams would give aid and advice to anyone within their area engaged in fighting a ship fire; if the occasion warrants, they could take part in the actual firefighting.

The same cache of equipment and the same high capacity pumps that would be available to the Seattle teams would also be available to these Coast Guard teams. Therefore, they also could transport equipment by helicopter and aid in fighting fires on ships near land. Simple prefire plans (as in the Fire Chief Expertise Plan) would be prepared, and advice could be given by radio to assist in fighting fires on ships at sea.

The principal differences between this plan and the Seattle plan are (1) the teams in the Seattle plan reside within the local fire

departments, whereas the Reserve units are part of the Coast Guard and (2) the Seattle plan team members are engaged full-time in marine fire protection, whereas the Coast Guard units are only on reserve duty. The Seattle team members spend much time preparing detailed prefire plans, but get little actual practice in fighting fires. The Coast Guard Reserve units are made up of professional firemen, involved daily in structural firefighting, but receiving only monthly training in marine firefighting as part of their reserve duty.

For the nationwide implementation of this program, we analyze the case of 24 Coast Guard Reserve teams located in the same areas as the 24 teams in the optimized Seattle plan. The cost of this program is estimated to be $1.04 million per year.

Ship Fire Officer Plan: The previous alternatives have concentrated on providing ship knowledge to land-based professional firefighters. A fundamentally different type of alternative is aimed at training ship officers in planning firefighting strategies; as noted in Chapter II, ship crews will soon receive firefighting training under the status quo. The program we propose would require two officers per U.S. flag ship (one deck officer and one engineering officer) to spend 1 extra week every 5 years at the fire school that all officers will be required to attend; in addition, these officers would be required to take a 2-day refresher course each year. The emphasis of this added training would be on the use of built-in fire suppression systems, the establishment of fire boundaries, and the organization and leadership of firefighting squads.

In addition to being valuable for fires fought at sea, this plan would be valuable for fires fought by land-based forces; the ship officer, because of his familiarity with fire problems and fire department terminology, could give considerable aid to the fire chief in command at the scene.

The cost of this program is estimated to be $1.48 million per year.

Instruct Ship Officer in Use of Built-in System: Built-in CO_2 or halon fire suppression systems are available on most modern ships and are extremely effective if properly used. However, serious ship fires are rare, and as a result, ship officers frequently do not maintain their knowledge of the procedures for correctly deploying the built-in systems. A simpler version of the preceding plan, aimed exclusively at the built-in systems, would provide instructors in port cities to review with U.S. and foreign flag ship officers the procedures for deploying built-in systems.

When a ship is in port, a ship officer would be instructed and certified in the use of the built-in fire suppression systems on his ship. This instruction would include proper use of the fire detection and location equipment, adequate sealing of ventilation, correct deployment of the built-in suppression system, and monitoring of the

temperature of the compartment. This program would increase the probability that the ship officer would decide to use the built-in system and the probability that he would use it correctly.

The cost of this program is estimated to be $0.5 million per year.

Redesign Built-in Systems: Another plan aimed exclusively at the built-in system concentrates on the system itself rather than the men who use it. With modern technology, the built-in system could be redesigned to make it easier to use. Such a system would have a single panel, easily accessible, that would integrate the fire location and detection system, ventilation and fuel pump controls, and the built-in fire suppression system controls. By pulling a single switch, the officer could secure the ventilation and deliver the agent to the correct compartment. The simplicity of this system would increase the probability of a command decision to use the system, and would virtually guarantee its correct use. Simple instructions for the follow-up procedures after deployment would be posted on the control panel. The cost of this program, for all U.S. flag ships (and only U.S. flag ships), is estimated to be $4.72 million per year.

Spray Collars in Engine Rooms: The preceding plans have been concerned almost entirely with fire suppression; the plan now described concerns fire prevention. A frequent cause of engine room fires is the failure of a joint in a high-pressure fuel, lubrication oil, or hydraulic fluid line; the spray that results is either ignited by a hot surface or it forms an aerosol which then explodes. Records show that 52% of engine room fires are caused by failures of these high-pressure lines. These fires account for over $10,000,000 of the expected annual loss for merchant vessels. A program is presently under way to install spray collars on the joints of all fuel, lubrication oil, and hydraulic fluid lines in the engine rooms of U.S. Navy ships; these spray collars contain sprays from joint failures and cause drips instead. The plan proposed here is the installation of these spray collars in the engine rooms of all U.S. flag freighter, container, tank, and passenger ships. The cost of this program is estimated to be $0.16 million per year.

Combinations of Above Programs: All combinations of the above programs are also analyzed in this study. The computerized model enables us to make this comprehensive examination of the 247 possible combinations of these individual alternatives.

Other Possible Programs: During this study, a number of other possibilities were identified as marine fire protection programs. Some of these programs are listed below, together with the reasons why they were not adopted as strategic alternatives competing with those above.

- Training of ship crews in firefighting techniques.
- Installation of inert gas systems in the cargo tanks of tankships to prevent explosions.

As discussed in Chapters II, VI, and IX, these programs were the subject of recent IMCO agreements and will be implemented in the next few years. These programs are therefore part of the status quo, 1980-2000.

- o Use of instructors of marine firefighting schools to provide expertise to municipal fire departments when ship fires occur.

This program is a modification of the Fire Chief Expertise plan for those port cities where marine firefighting schools are nearby. For this plan to work efficiently, a liason program would have to be established to give fire department chiefs familiarity with the program and confidence in the capability of the instructors to give sound advice at the scene of the fire. In any event, study of the cost figures show that the cost-effectiveness of this program would differ very little from that of the Fire Chief Expertise plan.

- o Design and construction of amphibious disaster vehicles to be used as fire trucks and, when needed, as low pumping capacity fireboats.

- o Use of portable high-capacity turbine pumps on tugboats to furnish a substitute for fireboats.

These two alternatives address the high cost of maintaining fireboats, by providing less costly substitutes. Insofar as these programs would replace existing fireboats, their effect is to reduce the cost of maintaining the status quo. (This topic is not within the scope of this study.) These programs can, however, supply fireboat capacity to ports that do not currently have fireboats; this possibility is discussed briefly in Chapter IV. It should be noted that five portable high-capacity turbine pumps, distributed on a regional basis, are included in the Seattle plan, the Fire Chief Expertise plan, and the Coast Guard Reserve plan.

- o Installation of high-resolution vessel traffic control systems to prevent collisions and hence fires caused by collision.

As discussed in Chapters II and VI, six such systems either are in place or soon will be in place. Coast Guard personnel have stated that these six locations are the only areas in the country in which such a system is cost-effective in preventing collisions. A possible refinement of radar-based, high-resolution vessel traffic control systems would be to provide a television monitor to pilots on ships in the area covered by the system.

- o Promulgation and enforcement of stricter "rules of the road" for vessels, particularly in congested areas.

- o Assignment of priority rights of way and "zones of avoidance" according to the hazard of the ship's cargo.

- Escorting of ships with very hazardous cargoes while these ships are in harbors.

These alternatives are also aimed at reducing the number of collisions and hence the number of collisions resulting in fire. At present, the Coast Guard provides an escort for LNG and munitions vessels in port. The effect of stricter "rules of the road" is discussed in Chapter IV; zones of avoidance and escorting of ships can be considered as a further refinement of this alternative.

- The use of bridge simulators to train pilots and masters of vessels in proper response to difficult emergency situations.
- The requirement that the emergency steering post be manned and that a crew member be kept at the anchor release during all maneuvers in congested areas.

These two plans are also aimed at reducing the number of collisions. The computerized simulators are very expensive and would not be cost-effective for the marine fire losses they would be expected to prevent; they might, however, be cost-effective in preventing collisions. The latter alternative is free, and should always be practiced.

- Requirement of a check list to verify the state of firefighting equipment before each voyage.

The historical records do not show that failure of firefighting equipment is a frequent problem. The principal equipment problem in fighting fires on ships is the incorrect use of the built-in fire suppression system; this problem is addressed in several of the alternatives we consider.

A final series of alternatives involves designing ships with improved fire prevention and fire suppression systems. Changes in ship design evolve over a long period of time. The measures below would most likely not have a substantial impact on the ship fire problem during the years of interest to this study (1980-2000).

- Design of fuel, lubricating oil, and hydraulic fluid lines so that, as far as possible, joints are not near hot surfaces. A more practical way to achieve these benefits is provided by the Spray Collar plan.
- Design of safe "citadels" in the engine room and on the bridge; from these protected vantage points, the ship crew can control fuel, ventilation, and power, and can use remotely controlled fire suppression systems to fight fires.

This plan would have its principal effect on tankship cargo fires, because serious engine room and cargo fires are even now normally fought from outside the compartments, with the use of built-in systems.

- Design of CO_2 systems that can be installed on a ship in modular form similar to a cargo container.

Such a system would simplify rapid checking or replacement of CO_2 systems; in addition, it would place the system and its controls on deck, making them accessible in almost any fire. The records, however, do not show a frequent problem in this regard.

- Installation of built-in CO_2 or halon systems on ships that do not have them.

Two surveys, one performed by SRI and the other performed during inspections by the American Bureau of Shipping, have shown that virtually all U.S. flag ships already have these systems installed in engine rooms and in those cargo holds that present a fire hazard. Almost as great a percentage of foreign flag ships are so equipped. It is largely the older ships that do not have this protection, and over the next 20 years, most of these ships will no longer be in service.

- Installation of fittings on cargo containers to allow application of CO_2 without opening the container.

This program would be effective in reducing the loss due to cargo fires aboard containerships. However, it would not reduce losses in incidents like the SS C.V. Sea Witch fire, where burning oil from the tankship SS Esso Brussels actually melted the containers. It is doubtful that it would be cost-effective to redesign all existing containers.

- Design of fire-resistant doors that allow the agent to be applied in compartments, without the door being opened.

Because built-in CO_2 or halon systems appear to be the most effective way of fighting engine room and cargo hold fires, this program would be most useful in superstructure fires. In these cases, records show that firefighters have often been unable to approach the fire because of heat and smoke. A septum in the door for the application of agent may help in fighting these fires since the door would not need to be opened.

- Modification of international salvage laws to facilitate prompt aid to ships that experience fires at sea.

There is no clear indication in the records that salvage laws play a large role in worsening the ship fire problem. In any event, changes in maritime law in this regard have ramifications in many different areas; a separate study would be required of all these areas to determine the overall cost-effectiveness of any change in the present law.

As mentioned in Chapter I, this study examines fundamentally different strategic approaches to reducing marine fire losses. The nine programs defined in this chapter and described in depth in Chapter X are the different strategic approaches we examine. The remaining sixteen programs, suggested by various individuals whom we interviewed, are piecemeal plans: several of these latter programs are applicable in only a few port areas; several would address only a small part of the problem; others are aimed not at reducing marine fire losses, but at decreasing costs of maintaining the status quo. As such, they do not meet the criteria of being broad-based strategic approaches to reducing marine fire losses on a nationwide basis. Should one or more of these suggestions prove cost-effective for an individual port area, they could be appended to the nine strategic programs and the hundreds of combinations thereof that we analyze in this study.

IV COST-EFFECTIVENESS OF THE MARINE FIRE PROTECTION PROGRAMS

In the previous chapters, the magnitude of marine fire losses has been described, a list of alternative programs to reduce these losses has been generated, and the model that calculates the benefits and costs of these programs has been outlined. In this chapter, the results of these calculations are reported, and the cost-effectiveness of the alternative programs are compared.

Decision Criterion

This cost-effectiveness analysis seeks to identify the marine fire protection program that minimizes "cost plus loss"; that is, the cost of the program plus the fire loss under that program.

The status quo alternative is the base case against which all other alternatives are compared; therefore, it is convenient to use the following formulation of the "cost plus loss" criterion. For each alternative, we compute both the expected increase in cost (relative to the status quo) and the expected reduction in loss (relative to the status quo). Subtracting the expected increase in cost from the expected reduction in loss, we determine the expected net savings of each alternative. Maximizing the expected net savings is equivalent to minimizing the expected cost plus loss.

As was mentioned in Chapter I, the net savings presented here are savings to society as a whole. The distributional question of who pays the cost and who enjoys the benefits should be debated only after the optimal program is identified.

Some of the costs of the proposed alternatives are initial capital outlays, and others are annual operating costs. To compare the different programs on an equal basis, we compute net savings on an equivalent annual basis, using an after-inflation interest rate of 5%. Appendix B presents an analogous set of results that lead to the same conclusions, but that use an after-inflation interest rate of 10%, as mandated by the Office of Management and Budget.

Cost-Effectiveness of Individual Alternatives

We are now in a position to evaluate each alternative. The probabilities and equivalent dollar losses presented in Chapters VI-X are entered into the decision tree of Figure I-1. The weighted average technique is then used to compute the expected net savings, just as it

was in Figure I-6 of the tutorial example. In the full-scale analysis, the decision tree is far more complex; there are millions of possible paths in Figure I-1 in contrast to the seven possible paths in Figure I-6.

The expected net savings for each of the eight individual programs listed in Chapter III are presented graphically in Figure IV-1 and in tabular form in Table IV-1; it should be remembered that all losses and costs are measured relative to the status quo, and hence, the status quo alternative has zero net savings.

Figure IV-1 shows that the three plans that supply expertise to land-based forces (Seattle, Fire Chief Expertise, and Coast Guard Reserve) achieve by far the greatest expected net savings. They have the highest net savings because (1) they greatly increase the probability that marine firefighting expertise will be available to the officer in command of the fire, (2) this expertise makes a substantial difference in the ability of the fire department to contain and extinguish the fire, and (3) a large fraction of fires, including most of the worst fires, occur at dock or in harbor, where land-based forces do the firefighting.

Low level marine firefighting training for the municipal departments, in contrast, yields less than half the savings of the Fire Chief Expertise plan. In small fires, low level training and expertise (differentiated in Chapter X) each improve firefighting effectiveness by approximately the same amount. In larger fires, expertise makes a big difference, but the low level training does not. The difference in effectiveness in the higher level fires explains the difference in net savings of these two fire department plans.

The three ship-based plans (Ship Fire Officer, Instruction on Built-in Systems, and Redesign Built-in Systems) have roughly equivalent net savings. The common element in these three plans is the increase in the probability that the built-in fire suppression systems are used correctly.

The differences between the three plans providing land-based expertise are more complex. The Fire Chief Expertise plan dominates these three plans because it provides on-duty battalion chiefs at all times in each of the 68 port cities, and these battalion chiefs respond more quickly to ship fires than the marine firefighting experts in the Seattle and Coast Guard Reserve plans. These latter two plans both offer the advantages of helicopter and radio assistance to vessels under way--a feature expected to save $1,000,000 per year. But even without this feature, the Fire Chief Expertise plan achieves the greatest expected net savings.

Compared to the Seattle plan, the Fire Chief Expertise plan is much cheaper. The Seattle plan requires 155 men full-time as opposed to the 300 men less than 2 weeks per year required by the Fire Chief Expertise

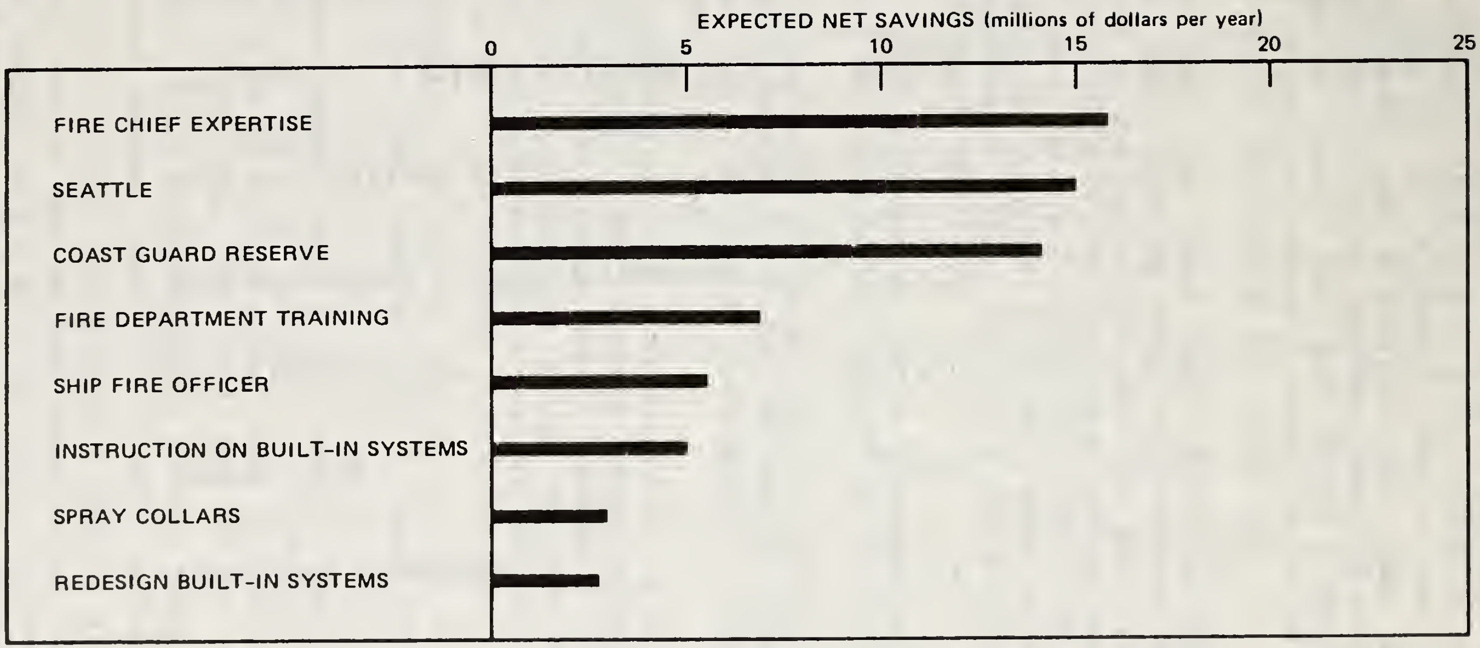


FIGURE IV-1 EXPECTED NET SAVINGS FOR INDIVIDUAL ALTERNATIVES

Table IV-I

COST-EFFECTIVENESS OF INDIVIDUAL ALTERNATIVES:

RANKING BY EXPECTED NET SAVINGS (MILLIONS OF DOLLARS PER YEAR)

Rank	Alternative	Expected Reduction in Loss	Expected Increase in Cost	Expected Net Savings
1	Fire Chief Expertise	17.7	2.0	15.7
2	Seattle Plan	20.0	5.0	15.0
3	Coast Guard Reserve	15.1	1.0	14.1
4	Fire Department Low Level Training	7.2	0.3	6.9
5	Ship Fire Officer	7.3	1.5	5.8
6	Instruction on Built-in Systems	5.6	0.5	5.1
7	Spray Collars	3.3	0.2	3.1
8	Redesign Built-in Systems	7.6	4.7	2.9
9	Status Quo	0.0	0.0	0.0

plan. In addition, the simple prefire plans of the Fire Chief Expertise plan are cheaper than the detailed prefire manuals prepared under the Seattle plan. In the opinion of most of the ship firefighting experts whom we interviewed, fire chiefs with expertise in ship firefighting would, with the aid of a simple plan of the ship's firefighting equipment, bulkheads, and access points, fight the fire almost as effectively as they would with the more detailed prefire plan. Finally, in cases where the Seattle team must travel 50 miles to reach a fire, its potential savings are reduced, especially in engine room fires where much damage is often done within the first hour.

Compared with the Coast Guard Reserve plan, the Fire Chief Expertise plan costs twice as much, but achieves significantly greater savings because of the faster response time and higher probability that the officer in command of the fire takes advice from a battalion chief than a Coast Guard Reserve firefighter. The Coast Guard Reserve teams will most likely be composed of firefighters rather than officers of local fire departments. Thus, the Fire Chief Expertise plan is the best of the individual alternatives.

Several other alternatives can be discussed at this point; each is described below and followed by a comment on cost-effectiveness.

- The preparation of simple prefire plans (as in the Fire Chief Expertise plan) and the use of these plans by the Coast Guard to provide firefighting advice by radio to vessels under way.

  The analysis of this alternative is an extension of the analyses above; the expected annual reduction in loss is \$850,000, the expected annual increase in cost is \$98,000; therefore, the expected annual net savings is \$752,000. Hence, the alternative is cost-effective, although not on the scale of the programs considered above.

- Promulgation of strict "rules of the road" to prevent collisions and, therefore, fires caused by collision.

  This alternative should be viewed as a collision-avoidance measure because most of the benefits apply to collisions where no fire is involved. Nevertheless, the model enables us to calculate that this alternative reduces ship fire losses by an expected \$1,000,000 per year.

- Use of portable high-capacity turbine pumps on tugboats to furnish fireboat capability to ports without fireboats.

  Analysis of this alternative indicates that the cost of buying such a pump exceeds the expected reduction in ship fire losses in the relevant ports. However, when marine firefighting training is provided together with these portable pumps, it becomes a break-even alternative.

Cost-Effectiveness of Combinations of Alternatives

Each of the eight strategic alternatives we have considered has positive expected net savings; therefore, many combinations can be expected to have positive net savings. As we observed earlier in Chapter II, the net savings of two plans combined may be less than the sum of the savings of each plan individually. The reason for this dilution is the overlap in the savings of the two plans.

From the eight individual programs, 247 unique combinations can be formed. However, by using an efficient search procedure, the program with the greatest expected net savings can be identified without evaluating all or even a large number of the 247 combinations.

Using the model, and taking care to avoid any double counting of savings, we determined that engine room spray collars, when added to any possible combination, increased total net savings. The same result was true for low level training for fire departments. Therefore, the spray collars and the low level training plan (either by itself or as provided by the Seattle plan) must be part of the optimal program. We also determined that exactly one of the land-based marine firefighting expertise plans must be included in the optimal program. Further, regardless of which of these combinations was formed, adding the ship officer plan would increase total net savings. The 12 possible combinations meeting these criteria were then evaluated and the optimum was identified.

As shown in Figure IV-2 and Table IV-2, this optimal program is a combination of the Fire Chief Expertise plan, Fire Department Low Level Training Plan, Ship Officer plan, Spray Collar plan, and Instruction on Built-in Systems plan. Expected net savings of eleven of the many possible combinations are graphed in Figure IV-2; expected net savings of a larger number of combinations are ranked in Table IV-2. The eleven combinations in Figure IV-2 were selected to show (1) the two combinations with the highest expected net savings, (2) the analogous combinations, but with the Seattle plan and the Coast Guard Reserve plan providing the land-based expertise and (3) the effects of combining subgroups of elements of the optimal program. These subgroups show the incremental net savings of the alternatives as they are combined to form the optimal program.

The first two entries in Figure IV-2 are the optimal program and the runner-up. The difference between them is the addition of instruction on the use of built-in systems. In this case, the savings of the instruction program are diluted because the Ship Officer plan would provide this instruction for officers on U.S. flag ships; adding the fifth element here is just barely cost-effective.

Of the $28.1 million reduction in loss from the optimal program, $27.1 million is saved in fires aboard merchant ships and $1.0 million in fires aboard the smaller merchant vessels.

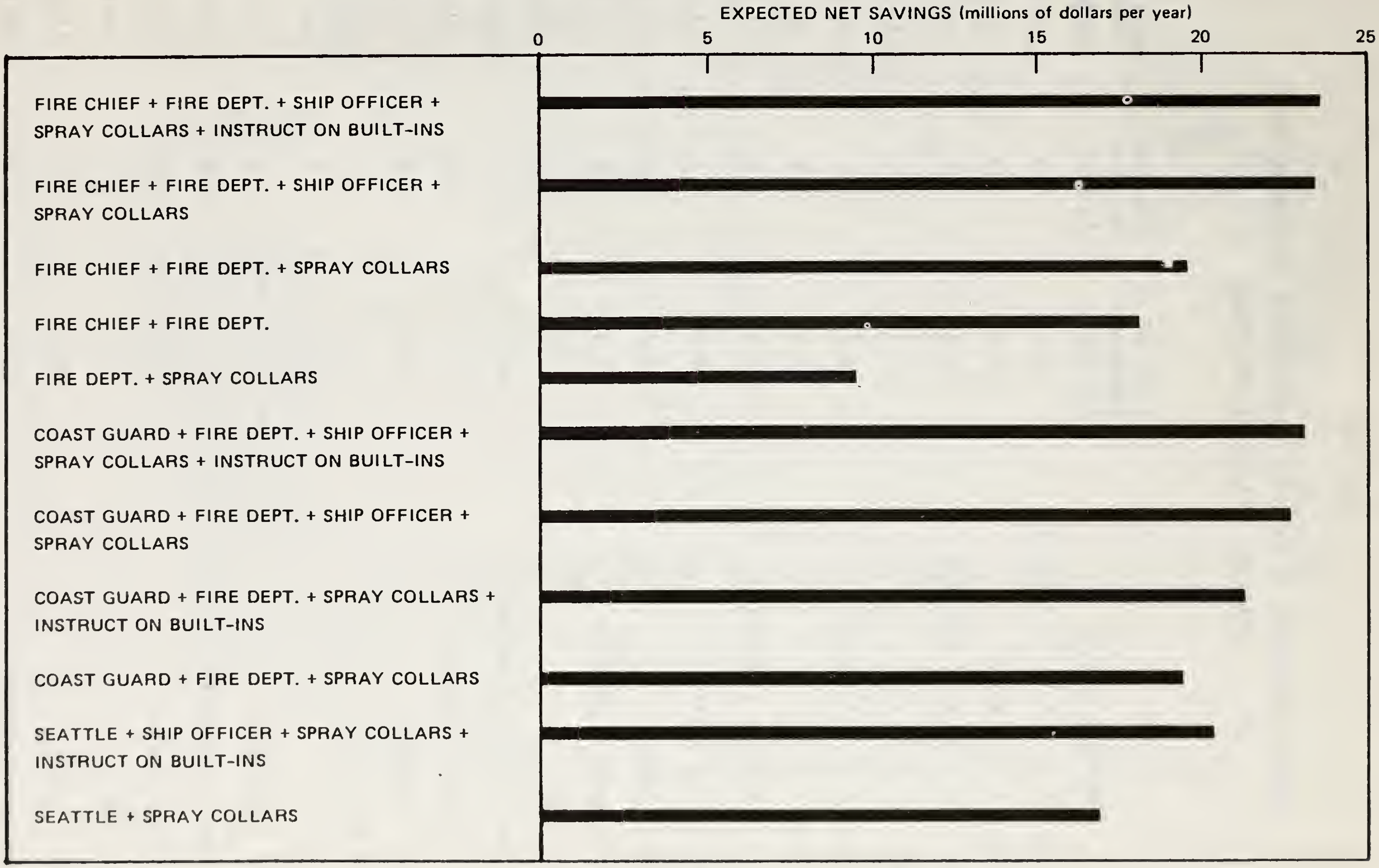


FIGURE IV-2 EXPECTED NET SAVINGS FOR SELECTED COMBINATIONS OF ALTERNATIVES

Table IV-2

COST-EFFECTIVENESS OF SELECTED COMBINATIONS OF ALTERNATIVES
(MILLIONS OF DOLLARS PER YEAR)

Combination Plan	Expected Reduction in Loss	Expected Increase in Cost	Expected Net Savings
Chief + Dept + SO + Spray + Instruct*	28.1	4.5	23.6
Chief + Dept + SO + Spray	27.5	4.0	23.5
CG + Dept + SO + Spray + Instruct	26.6	3.5	23.1
CG + Dept + SO + Spray	25.7	3.0	22.7
Chief + Dept + SO + Instruct	26.6	4.3	22.3
Chief + Dept + SO	25.9	3.8	22.1
Chief + SO + Spray + Instruct	26.0	4.2	21.8
CG + Dept + SO + Instruct	25.0	3.3	21.7
Chief + SO + Spray	25.2	3.7	21.5
CG + Dept + Spray + Instruct	23.3	2.0	21.3
CG + Dept + SO	24.0	2.8	21.2
Chief + Dept + Spray + Instruct	24.2	3.0	21.2
CG + SO + Spray + Instruct	23.7	3.2	20.5
Chief + SO + Instruct	24.4	4.0	20.4
Seattle + SO + Spray + Instruct	27.5	7.2	20.3
Chief + SO	23.5	3.5	20.0
CG + Dept + Instruct	21.6	1.8	19.8
Chief + Dept + Instruct	22.5	2.8	19.7
Chief + Dept + Spray	22.1	2.5	19.6
CG + SO + Spray	22.3	2.7	19.6
CG + Dept + Spray	20.9	1.5	19.4
Chief + Spray + Instruct	22.0	2.7	19.3

Table IV-2 (Concluded)

CG + SO + Instruct	21.9	3.0	18.9
CG + Spray + Instruct	20.2	1.7	18.5
Seattle + SO	25.0	6.5	18.5
Chief + Dept.	20.2	2.3	17.9
CG + SO	20.3	2.5	17.8
Chief + Spray	19.7	2.2	17.5
Seattle + Spray	22.0	5.2	16.8
CG + Instruct	18.3	1.5	16.8
CG + Dept	17.8	1.3	16.5
CG + Spray	17.3	1.2	16.1
Dept + SO + Spray + Instruct	18.5	2.5	16.0
Chief + Instruct	18.2	2.5	15.7
Dept + SO + Spray	16.3	2.0	14.3
Dept + SO + Instruct	16.5	2.3	14.2
Dept + Spray + Instruct	13.7	1.0	12.7
Dept + SO	14.0	1.8	12.2
Dept + Instruct	11.4	0.8	10.6
Dept. + Spray	9.9	0.5	9.4

*LEGEND

Chief - Fire Chief Expertise Plan
Dept - Fire Department Low Level Training Plan
CG - Coast Guard Reserve Plan
Spray - Spray Collars in Engine Rooms Plan
Instruct - Instruction on Built-in Systems Plan
SO - Ship Fire Officer Plan
Seattle - Seattle Plan

One combination of particular interest is the Fire Chief Expertise plan together with the Fire Department Low Level Training plan. This program is a very natural combination residing entirely within the fire department; it also approximates the Seattle plan, because the Seattle marine firefighting teams would provide low level training to local fire departments in their regions. It should be noted that the expertise plus low level training program residing within the existing fire department structure is significantly more cost-effective than the regional firefighting team program. Figure IV-2 shows that this greater cost-effectiveness is always maintained as other elements are added in building the optimal marine fire protection program.

Sensitivity of Ranking of Alternative Plans to Critical Judgments

The remaining task in evaluating the alternative marine fire protection programs is to determine the sensitivity of the ranking of the alternatives to the many assessments made in building the model. From a decision-making viewpoint, the critical judgments in the analysis are those that, with slight variation, could reverse the ordering of the most attractive alternatives.

Sensitivity analysis using the complete model showed that reasonable variations in the parameters of the Fire Scenario Model do not alter the ranking of the leading alternatives. The alternatives fall into groups that achieve their savings on the same types of fires; a change in the number of these fires shifts the savings in each group of alternatives in the same direction. Furthermore, the parameters of this model are quite well determined by historical data. The most uncertain data concern the frequency with which a Texas City type of port catastrophe can be expected. Table IV-3 shows the amount by which each alternative reduces port catastrophe losses. Increasing or decreasing the probability of the port catastrophe would not change the ranking of the best alternatives or combinations of alternatives.

Similarly, Table IV-3 shows that all the leading alternatives reduce losses in the same categories. Therefore, there is little sensitivity to the parameters of the Value Model. In addition, the dollar values used in this model are derived from actual known losses. The value assigned to human death and injury, however, is a measure of society's attitude toward the amount of resources that should be allocated to prevent death or injury. If the values associated with human death and injury were increased tenfold, with human deaths valued at $3,000,000 and injuries at $300,000, we would find the results presented in Figure IV-3. The optimal program does not change; however, its expected net savings would increase to $42.5 million. The important point is that the ranking of the most attractive alternatives remains unchanged.

The ranking of the alternatives is not sensitive to reasonable changes in the parameters of the Cost Model because the cost of

Table IV-3

BREAKDOWN OF REDUCTION OF LOSS FOR
INDIVIDUAL PLANS (MILLIONS OF DOLLARS PER YEAR)

Alternative	Vessel	Cargo	Human	Waterfront, Commercial	Port Catastrophe	Total
Fire Chief Expertise	7.9	2.4	1.2	1.9	4.3	17.7
Seattle Plan	9.4	2.9	1.4	1.9	4.4	20.0
Coast Guard Reserve	7.2	2.2	1.0	1.4	3.3	15.1
Fire Department Low Level Training	3.1	1.1	0.5	0.8	1.7	7.2
Ship Fire Officer	4.0	1.7	0.8	0.3	0.5	7.3
Instruction on Built-in Systems	2.6	1.1	0.4	0.5	1.0	5.6
Spray Collars	2.3	0.4	0.2	0.2	0.2	3.3
Redesign Built-in Systems	3.7	1.6	0.6	0.6	1.1	7.6

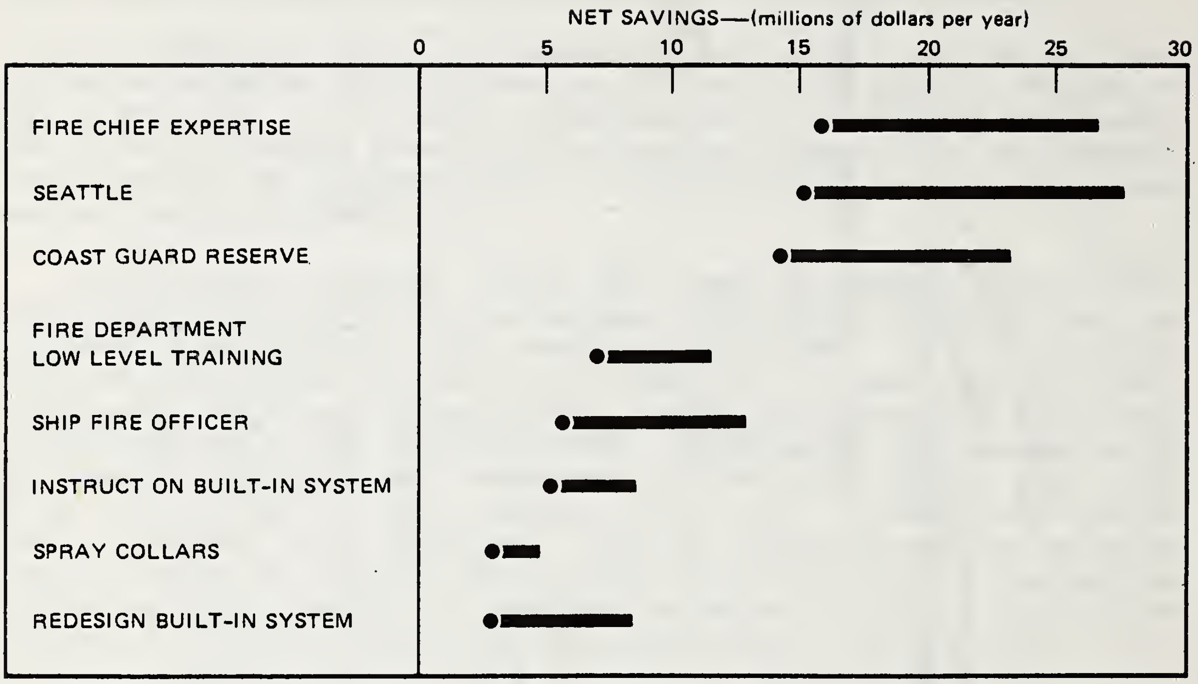


FIGURE IV-3 SENSITIVITY OF RANKING OF ALTERNATIVES TO TENFOLD INCREASE IN VALUE ASSIGNED TO HUMAN DEATH AND INJURY

implementing the programs is small compared with the reduction of loss for the leading alternatives. In addition, the same costs were used for training, equipment, and salaries for all the alternatives; reasonable changes here affect all the alternatives in a similar manner.

The Firefighting Performance Model is the area where expert judgments were most critical. For each alternative, these judgments included (a) the probabilities that the various levels of marine firefighting expertise and training would be found among firefighting forces both on land and at sea, (b) the probabilities that these levels of expertise and training would be on the scene and effective in each ship fire, (c) the probabilities that firefighters with these levels of expertise and training could use the built-in system correctly, and (d) the probabilities that firefighters with these levels of expertise and training could extinguish each ship fire at its initial level of involvement. The probability assessments in (c) and (d) are the consensus of numerous experts; further, they are constrained in that they must combine to reproduce the known historical fire losses. The probabilities in (a) are determined by the definition of the alternatives. The probabilities in (b) are crucial. They determine the key differences between each alternative and the status quo. Sensitivity of the ranking of the alternatives to 10% changes in these probabilities is shown in Figure IV-4.

Because many of the arguments used in assessing these probabilities were similar for comparable alternatives, it is unlikely that underestimates occurred in some cases and overestimates in others. For this reason, reasonable and likely variations shift comparable alternatives in the same direction, and do not change their ranking.

Finally, the ranking of the most attractive alternatives is not sensitive to an increase or decrease of 5 percentage points in the interest rate used in determining equivalent annual costs and losses. Appendix B shows the results analogous to Table IV-1 but with expected net savings discounted at an after-inflation rate of 10%.

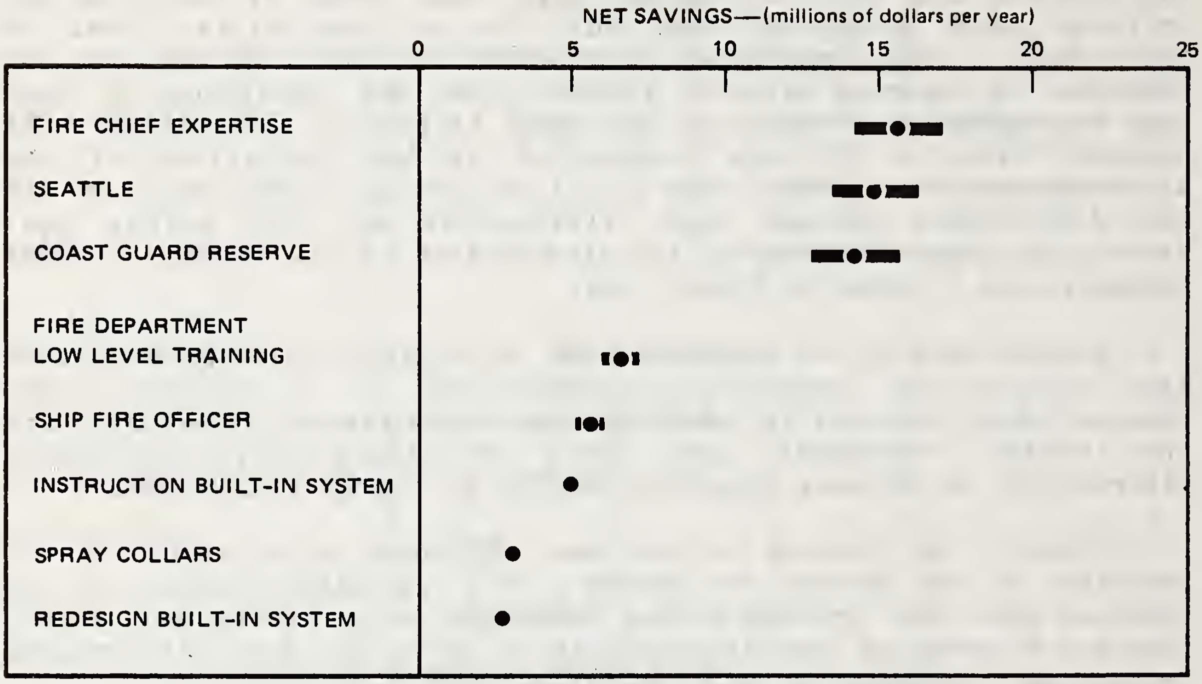


FIGURE IV-4 SENSITIVITY OF RANKING OF ALTERNATIVES TO ASSESSMENT OF LEVELS OF EXPERTISE AND TRAINING IN MARINE FIREFIGHTING

V CONCLUSIONS

Magnitude of Marine Fire Problem

The first task in this study was to estimate the magnitude of current marine fire losses. We estimated that current marine fire losses average $74.6 million per year. We also estimated that because of new trends in the maritime industry, this figure would grow to $99.5 million per year for the period 1980-2000 if the current marine fire protection system was to remain unchanged. Although marine fire losses make up only a small fraction of marine losses from all causes and an even smaller fraction of fire losses of all types*, the need for improved marine fire protection has been of concern to several parties and a number of new programs in this area are already being or will soon be implemented. We estimated that these new programs will reduce marine fire losses over the next 20 years to an average of $77.4 million per year.

Alternatives Considered

The second task in this study was to develop a wide range of fundamentally different strategic approaches to improving marine fire protection. In the initial phase of this study, we developed a long list of possible programs. Preliminary analysis identified those programs on this list that either had little impact on the marine fire problem or were clearly not cost-effective. These programs were removed from the list. We then selected broad strategic alternatives that represented the key concepts of all the remaining programs. The final set of alternatives was (a) the plan proposed to Congress in H.R. 11459 (the Seattle plan), which calls for regional marine firefighting teams, prefire planning of vessels, and helicopter and radio firefighting assistance to vessels under way, (b) a plan to develop marine firefighting expertise among chiefs in municipal fire departments in

---

* U.S. Coast Guard data from 1963-1976 indicate that fire and explosion losses account for 12% of all marine losses. However, this figures does not include fires resulting from collision, nor does it include any contribution to loss from the Texas City type of port catastrophe. Using National Fire Protection Association data for 1976, adjusting for inflation to 1975 constant dollars, and placing a value on human deaths and injuries of $300,000 per death and $30,000 per injury to produce figures comparable to our estimates, we find that total fire losses in the United States in 1976 were $6.8 billion.

U.S. port cities, (c) a plan to provide low level marine firefighting training for members of municipal fire departments in U.S. port cities, (d) a plan to develop marine firefighting expertise in U.S. Coast Guard Reserve units in U.S. port cities, (e) a plan to teach firefighting strategy to officers on U.S. flag ships, (f) a plan for instructing officers aboard all merchant vessels (U.S. flag and foreign flag) in the use of built-in fire suppression systems, (g) a plan to redesign the built-in fire suppression systems on U.S. flag ships, (h) a plan to install spray collars in the engine rooms of U.S. flag ships, and (i) the hundreds of possible combinations of these eight individual plans. In the early phases of the study, tanker inerting and ship crew firefighting training were also considered as alternatives. However, these latter programs were adopted or will soon be adopted by the maritime industry; consequently, they are no longer considered as decision alternatives, but rather as part of the status quo alternative for the years 1980-2000.

Cost-Effectiveness

The third task in this study was to compare the cost-effectiveness of each of the different marine fire protection programs. By constructing a quantitative model of ship fires, firefighting effectiveness, and fire losses, we were able to estimate the expected net savings of each individual program and each combination of programs. The best program, that with the highest expected net savings, was found to be a combination of the following five elements:

(1) Develop marine firefighting expertise among battalion chiefs in municipal fire departments of U.S. port cities.

(2) Provide low level marine firefighting training for members of municipal fire departments of U.S. port cities.

(3) Teach shipboard firefighting strategies to ship officers of U.S. flag vessels (this instruction is in addition to the firefighting training all officers will receive as part of the status quo).

(4) Install spray collars in engine rooms of U.S. flag ships.

(5) Instruct officers on foreign flag ships, while in U.S. ports, in the use of built-in systems.

As Table IV-2 showed, the addition of the fifth item to a program including the first four is just barely cost-effective; therefore, a more detailed study of this fifth element should be carried out before any plans are made to implement it, particularly as it may involve political problems.

The optimal fire prevention and fire suppression program above has expected annual net savings of $23.6 million; it has an expected annual reduction in loss of $28.1 million, and an expected annual cost of $4.5 million. It should be noted that this alternative remains the optimal alternative even if the contribution from the port catastrophe is excluded.

Our model allowed us to compute the efficiency of the fire suppression elements of any of the programs. By definition, a 100% efficient fire suppression system would extinguish every fire at its initial level; fire suppression, of course, cannot undo damage done in the initial stages of a fire before firefighting begins. The optimal program above has a suppression efficiency of 69%; that is, the reduction in losses is 69% of that of the ideal 100% suppression system (for ships, excluding smaller vessels). It should be noted that in this case, even a 100% efficient suppression system on ships would result in total fire losses of $39.6 million; this is the sum of $22.2 million from fires on smaller vessels and $17.4 million from damage done in the initial stages of fires on ships. Prevention measures are the only practical means of further reducing loss. The Coast Guard currently enforces numerous fire prevention measures and will enforce the tanker inerting standards and the vessel traffic control systems as part of the status quo for 1980-2000. The only new cost-effective ship fire prevention measure we identified was the installation of spray collars in engine rooms.

A modification of the Fire Chief Expertise component of the optimal program could make the entire program more cost-effective. This modification would broaden the scope of the program to cover all transportation and hazardous cargo fires as opposed to ship fires alone. Fires in ships, trains, and trucks have several common features; therefore, the battalion chiefs who are given expertise in fighting fires aboard ships could at the same time, and at little additional cost, be given expertise in fighting the tank car and tank truck fires that are much more frequent. An outline of such a plan is presented in Appendix C.

Proposal of such a plan that reaches beyond marine fire protection was not called for in this study. However, numerous fire chiefs we interviewed during the course of the study expressed their concern over both the increasing number of serious transportation fires of all types and the urgent need to develop expertise within their departments in fighting these fires. The modification proposed here would provide all the advantages of our Fire Chief Expertise alternative, but would also reduce losses in other transportation and hazardous cargo fires.

Ship Fire Records

One other set of conclusions concerns the national data base for ship fires. Appendix D summarizes the adequacy of the existing data base and suggests improvements that could be made.

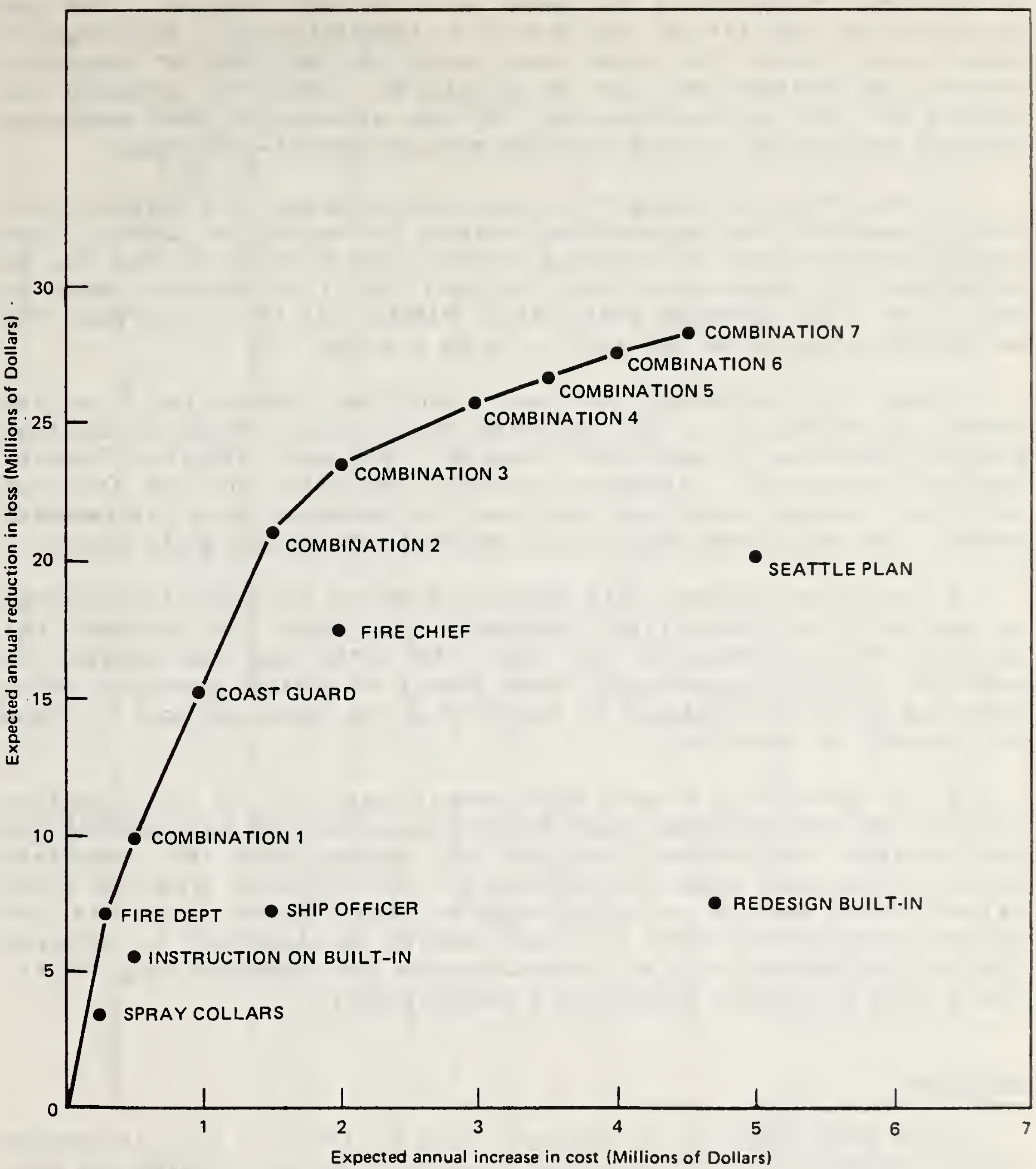
The Benefit-Cost Ratio

Thus far in the analysis, the objective has been to select the alternative that maximizes expected net savings. In cost-effectiveness analyses, consideration is often given to the benefit-cost ratio, as well as to net savings. It is important to emphasize that the benefit-cost ratio alone is not a sufficient criterion for rational choice among a portfolio of alternatives. The benefit-cost ratio may be useful, however, as a constraint imposed upon the objective of maximizing net savings; this constraint is normally stated as a minimum benefit-cost ratio required for each increment of investment.

Figure V-1 enables us to identify the program that maximizes expected net savings subject to such a constraint on the benefit-cost ratio. Each point on the graph represents an expected reduction in loss (its component along the vertical axis) and an expected increase in cost (its component along the horizontal axis). The expected net savings of each alternatives is, therefore, its vertical component minus its horizontal component.

The broken line in Figure V-1, curving from the lower left corner to the upper right, is what we call the cost-effective frontier. This frontier includes all alternatives that maximize expected net savings for some minimum benefit-cost ratio. Alternatives inside this frontier, that is, below and to the right of the broken line, would not be chosen since those on the frontier are more cost-effective--the alternatives on the frontier achieve a greater reduction in loss at the same cost (or the same reduction in loss at a lower cost).

The cost-effective frontier in figure V-1 shows how the optimal program is built up from the individual alternatives. The first point on the frontier is the Fire Department Low Level Training program. It has an expected reduction in loss of $7.2 million and an expected cost of $0.3 million; its expected benefit-cost ratio of 24 is the highest of all the alternatives. Having made this attractive investment, we can obtain an additional expected reduction in loss of $2.7 million for an additional expected cost of $0.2 million by combining the Spray Collar program with the Fire Department Low Level Training program (see Table IV-2). The ratio of incremental benefit to incremental cost from adding the Spray Collar program is 13.5, making it the most attractive incremental investment. This combined program is represented by the point labeled Combination 1 on the frontier.



LEGEND: Combination 1: Fire Dept + Spray Collars
Combination 2: Fire Dept + Spray Collars + Coast Guard
Combination 3: Fire Dept + Spray Collars + Coast Guard + Instruction on Built-in
Combination 4: Fire Dept + Spray Collars + Coast Guard + Ship Officer
Combination 5: Fire Dept + Spray Collars + Coast Guard + Ship Officer + Instruction on Built-in
Combination 6: Fire Dept + Spray Collars + Fire Chief + Ship Officer
Combination 7: Fire Dept + Spray Collars + Fire Chief + Ship Officer + Instruction on Built-in

FIGURE V-1 PORTRAIT OF COST-EFFECTIVENESS

The same analysis of incremental benefit and incremental cost can be performed sequentially for each point on the frontier, from the status quo alternative all the way up to Combination 7. The range of benefit-cost ratios for which each point on the frontier maximizes expected net savings can also be calculated. Table V-1 presents the results of this calculation--that is, the alternative that maximizes expected net savings for any required minimum benefit-cost ratio.

In this study of marine fire protection programs, the objective has been to maximize the expected net savings to society at large. This objective corresponds to a minimum benefit-cost ratio of 1; that is, an expenditure of ninety-nine cents is justified if it reduces losses by one dollar. The reasoning behind this objective is that the greater the net savings, the better off society is as a whole.

Using this criterion, we have identified Combination 7 as the optimal alternative; it has expected net savings of $23.6 million, greater than that of any other program. The cost-effective frontier ends at Combination 7 since the expected reduction in loss from any additional element would be less than its expected cost (incremental benefit-cost ratio less than 1) and expected net savings would decline.

As mentioned earlier, this analysis examines the cost-effectiveness of marine fire protection programs, but does not address the distributional question of who pays the costs and who shares the benefits. This distributional issue should be studied carefully and a mechanism should be designed to ensure that the costs are paid by those who receive the benefits.

It is interesting to note that several points on the cost-effective frontier include the Coast Guard Reserve plan, but the two combinations that achieve the greatest expected net savings have the land-based marine firefighting expertise provided by the Fire Chief Expertise plan. As mentioned earlier in this chapter, this latter plan has the additional feature that it could easily be modified to provide firefighting expertise in all transportation and hazardous cargo fires, thus making the entire program more cost-effective.

Epilogue

This study began as an analysis of H.R. 11459, a bill introduced before Congress in 1976 proposing a national marine firefighting plan modeled after the pilot project conducted in Seattle and the Puget Sound area. Having performed this comprehensive analysis of alternative marine fire protection programs, we can provide some general comments about the plan in the proposed legislation. First, the fundamental idea embodied in the Seattle plan is the development of land-based marine firefighting expertise. Without question, our analysis has shown that land-based marine firefighting expertise is the backbone of each of the most cost-effective alternatives. In this respect, we have demonstrated

Table V-I

OPTIMAL ALTERNATIVE FOR ANY BENEFIT-COST RATIO*

Required Minimum Benefit-Cost Ratio	Optimal Alternative
1.0 to 1.2	Fire Dept + Spray Collar + Fire Chief + Ship Officer + Instruction on Built-in
1.2 to 1.8	Fire Dept + Spray Collar + Fire Chief + Ship Officer
1.8 to 1.9	Fire Dept + Spray Collar + Coast Guard + Ship Officer + Instruction on Built-in
1.9 to 2.4	Fire Dept + Spray Collar + Coast Guard + Ship Officer
2.4 to 4.7	Fire Dept + Spray Collar + Coast Guard + Instruction on Built-in
4.7 to 11.0	Fire Dept + Spray Collar + Coast Guard
11.0 to 13.5	Fire Dept + Spray Collar
13.5 to 24.0	Fire Dept
24.0 and above	Status Quo

LEGEND:

Fire Dept - Fire Department Low Level Training plan
Spray Collar - Spray Collar plan
Fire Chief - Fire Chief Expertise plan
Ship Officer - Ship Fire Officer plan
Instruction on Built-in - Instruction on Built-in Systems plan
Coast Guard - Coast Guard Reserve plan

* The optimal alternative is the alternative that maximizes expected net savings subject to the constraint that the benefit-cost ratio must be greater than or equal to the required minimum.

the importance of the key concept of the Seattle plan. However, the Seattle plan as designed, with regional full-time marine firefighting teams and detailed prefire plans, is not as cost-effective, either alone or in combination with other plans, as the Fire Chief Expertise plan. This latter plan, with marine firefighting expertise for fire department chiefs and simple prefire plans, achieves approximately the same expected reduction in loss as the Seattle plan, but at a much lower expected cost; in addition, it could easily be broadened in scope to provide firefighting expertise for all transportation and hazardous cargo fires.

PART TWO

METHODOLOGY AND DATA

This part of the report presents the methodology, data, and assessments that provide the basis for the results summarized in Part One. Just like the systems model in Figure I-2, this section is divided into the 5 logical parts of the problem: the Fire Scenario Model, the Fire Involvement and Damage Model, the Value Model, the Firefighting Performance Model, and the Decision Alternatives and Cost Model. All of the final data used in each of these models are included in the appropriate section. All of the methodology used in generating the data required for each model is also explained in the appropriate section.

Only a sampling of the raw data assembled in preparing the final data is included. The raw data is contained in thousands of pages of historical records and summaries of interviews with experts. We have included a description of all sources of historical data and expert judgment used in each model, together with a description of the method of converting the raw data to the form required for the analysis. SRI will provide the original data to the sponsoring agencies or other interested parties upon request.

VI FIRE SCENARIO MODEL

To assess systematically the expected impact of alternative marine firefighting programs, we must carefully distinguish the different kinds of marine fires and estimate how often they occur. The Fire Scenario Model does both of these tasks, distinguishing different types of ship fires sufficiently for assessment of firefighting performance and measurement of dollar damages, and providing the relative likelihood of each type of ship fire and the average number of ship fires per year.

In building such a model, a balance must be reached between the degree of detail needed to describe the unique aspects of a given ship fire and the resulting complexity of the analysis, because the number of assessments grows geometrically with the number of parameters. After lengthy discussions with marine firefighting personnel, we agreed on a minimal set of five parameters required for assessing firefighting performance: ship type, ship location, fire location, fire development, and built-in fire suppression systems.

First, the type of ship in which the fire occurs must be specified to determine its configuration, the fire properties of its cargo, and the firefighting training of its crew. Second, the location of the ship at the time the fire occurs must be specified to determine whether the fire is fought by the crew or by land-based firefighters. Third, the location of the fire aboard the vessel must be specified to determine the fire characteristics, the speed at which the fire can spread, the difficulty in gaining access, and the techniques useful in fighting the fire. Fourth, the type of fire development (either explosion, rapid, slow, or resulting from collision) must be specified because it greatly affects the initial challenge facing the firefighters. Fifth, the existence of a built-in volume flooding extinguishing system in the compartment in which the fire occurs must be specified. In many types of fires, these systems are far superior to manual firefighting. For tankships, the existence of inerting systems in cargo tanks and fixed foam systems on deck must also be specified.

Two additional parameters are required to assess dollar losses: the ship's size and age. For a given ship type, the size is needed to determine cargo carrying capacity and new replacement cost. Given new replacement cost, the ship's age provides the basis for estimating its current market value. These seven descriptors make up the Fire Scenario Model; each is described in more detail in the following section.

The data base used to build the Fire Scenario Model was 14 years of Coast Guard records of vessel fires, explosions, and collisions

resulting in fire. The key assumption made here is that this data can be used to predict the number of ship fires for several years into the future. For 1980-2000, however, the period considered in this study, various trends and programs now getting under way will change the number and type of fires that would otherwise be expected; these trends are incorporated into our data at the end of this chapter in the section entitled Fire Scenario Data for the Status Quo Base Case, 1980-2000.

Elements of the Fire Scenario Model

Each of the seven elements of the Fire Scenario Model must be categorized precisely before quantitative estimates can be made.

Ship Type

We have gathered all types of merchant vessels into nine broad categories reflecting the size and complexity of the ships and the nature of the fires to be fought aboard them. The nine categories are:

- Freighters: general cargo, break bulk, and bulk carriers (except tankers).
- Containerships: container, freight car carriers, and ro-ro vessels.
- Tankers: crude oil, petroleum products, and flammable chemical carriers.
- Passenger ships over 65 feet in length.
- Tank barges: nonselfpropelled crude oil, petroleum product, and flammable chemical carriers.
- Cargo barges.
- Tugboats, towboats, work vessels, utility vessels, dredges, and construction vessels.
- Fishing boats, excluding sport fishing and charter fishing craft.
- Miscellaneous: supply craft, ferries, passenger vessels less than 65 feet, and other ships not classified above (e.g., research ships), but not including small pleasure craft.

As mentioned in the Introduction, no vessels owned or operated by military forces are included in the above categories. U.S. flag ships are included at all times, whereas foreign flag ships are included only when in U.S. ports or waters.

Ship Size

Several size categories were chosen to represent the spectrum of ship sizes for each type of U.S. flag merchant vessel or foreign flag merchant vessel visiting U.S. ports.

o Freighter: $<$ 7,500 deadweight tons (Dwt).
7,500 - 15,000 Dwt.
$>$ 15,000 Dwt.

o Container: $<$ 15,000 Dwt.
15,000 - 21,000 Dwt.
21,000 - 26,000 Dwt.
$>$ 26,000 Dwt.

o Tanker: $<$ 20,000 Dwt.
20,000 - 50,000 Dwt.
50,000 - 100,000 Dwt.
$>$ 100,000 Dwt.

o Passenger: $<$ 1,000 gross tons (Gt).
1,000 - 10,000 Gt.
$>$ 10,000 Gt.

An average size only was chosen for smaller vessels.

o Tank barge: 150 ft.

o Cargo barge: 150 ft.

o Tugboat, towboat, utility vessel: Harbor size

o Fishing boat: 100 tons

Ship Age

Ages of vessels are divided into three groups:

o Less than 5 years old

o 5 - 10 years old

o Greater than 10 years old.

Ship Location

The location of the ship must be described accurately enough to determine whether land-based or ship-based personnel fight the fire and whether damage to waterfront facilities can result. The following four categories meet these needs:

- At dock in a U.S. harbor: also includes vessels in dry dock or being repaired in a shipyard.
- In a U.S. harbor, not docked, but within reach of land-based firefighting forces--e.g, by fireboat.
- Near land, but beyond the reach of conventional land-based firefighting forces (includes harbors without fireboat protection).
- At sea or in foreign ports or waters.

Fire Location

The numerous compartments aboard a ship are grouped into the following three spaces, each with fundamentally different fire characteristics. The categories are broad, but provide a breakdown sufficient for assessment of firefighting performance, damage, and value.

- Engine: includes all machinery spaces with the exception of the pump rooms on a tanker.
- Cargo: includes the cargo holds and deck cargo areas on dry cargo vessels, and the cargo tanks, pump rooms, and piping on tankers.
- Superstructure: includes the living spaces, galley, crew stores, and bridge.

Fire Development

The manner in which the fire starts and the rate at which it burns are classified as one of four fire developments:

- Explosion: the rupture of pressure vessels or the explosive ignition of vapors.
- Rapid: characteristic of flammable liquid fires, electrical fires, or loosely-packaged combustibles.
- Slow: characteristic of most dry cargo fires.
- Collision-induced: this category is used only when a collision ruptures the cargo tanks of a tanker or tank barge and causes a fire on either or both ships involved.

Built-in Systems

Many vessels today are fitted with built-in CO_2 or halon volume flooding fire suppression systems in the engine room and/or the cargo holds. In addition, many tankers have foam systems installed to help

combat flammable liquid fires. These are the only systems we categorize as "built-in systems." The existence of other fire suppression equipment such as fire mains, hand lines, or portable extinguishers is taken into account in the assessments in the Firefighting Performance Model. Whether a cargo tank inerting system is in place on a tankship is also recorded in the Fire Scenario Model.

Fire Scenario Data for the Status Quo Base Case, 1975

The first step in developing the data for the Fire Scenario Model is measuring the relative likelihood of each fire scenario for the status quo base case for 1975. Figures VI-1 and VI-2 present the final fire scenario data in probability tree form. The probability tree structure shows the probability of each characteristic and the dependencies among the seven elements of the Fire Scenario Model.

Figure VI-1 shows, for example, that there are 22.4 fires per year aboard freighters; of these 22.4 fires, 59% occur at dock, 7% in harbor (but not docked), 5% near land, and 29% at sea. Of those at dock, 47% are engine room fires, 35% are cargo hold fires, and 18% are superstructure fires. Of these engine room fires, 26% were explosions, and 74% were rapid. The number of rapid engine room fires aboard docked freighters per year is then the product of the fire frequency and each of the relevant conditional probabilities from the tree:

$$(22.4) \times (0.59) \times (0.47) \times (0.74) = 4.6$$

Thus, on the average, there are 4.6 rapid engine room fires aboard docked freighters per year. The frequency of fires for each ship type and the conditional probabilities of ship location (given ship type), fire location (given ship type and ship location), and fire development (given ship type, ship location, and fire location) are presented in Figure VI-1. The complete Fire Scenario Model is developed for merchant vessels; for barges, fishing boats, tugs, tows, and miscellaneous ships, only the level of detail needed for assessment of firefighting performance and value is developed.

Figure VI-2 shows the percentage of fires by size and age groups for each type of merchant vessel. For example, 52% of tanker fires occur on tankers of 20,000-50,000 Dwt. and 72% of tanker fires occur on vessels over 10 years old. Again, less effort was devoted to the less complex case of fishing boats, barges, and tugs. One average size only was chosen for each of these smaller vessels, as indicated earlier in the ship size definitions; the distribution of fires by age for dry cargo vessels is assumed to hold for dry cargo barges, fishing boats, and tugs, and that for tankers is assumed to hold for tank barges.

The primary sources of the information shown in Figures VI-1 and VI-2 are 14 years of U.S. Coast Guard records of fire and explosion (fiscal years 1963-1976), 9 years of U.S. Coast Guard Marine Board of

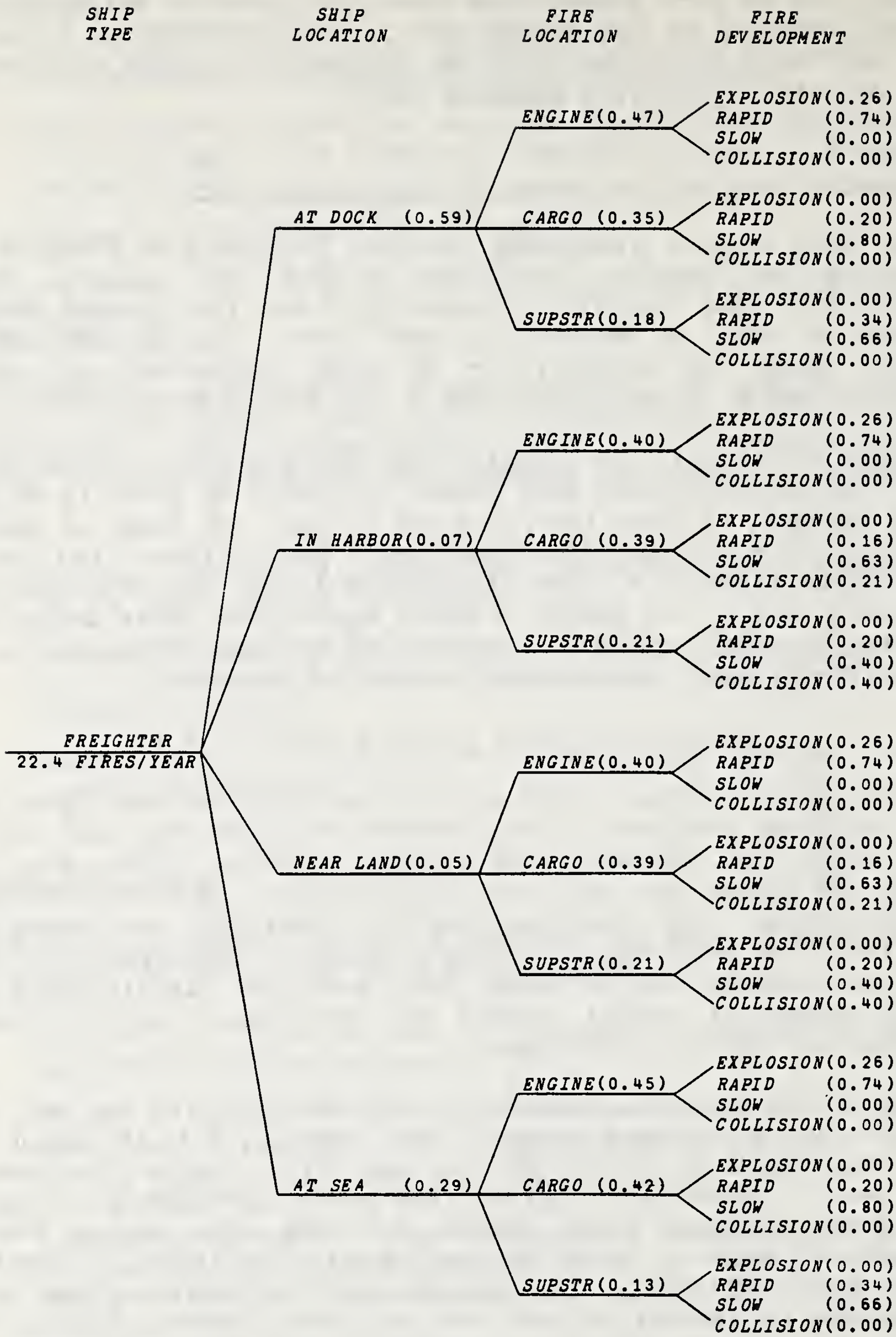


FIGURE VI-1 STATUS QUO, 1975: FREQUENCY OF FIRES BY SHIP TYPE AND CONDITIONAL PROBABILITIES (IN PARENTHESES) OF FIRES, BY SHIP LOCATION, FIRE LOCATION, AND FIRE DEVELOPMENT

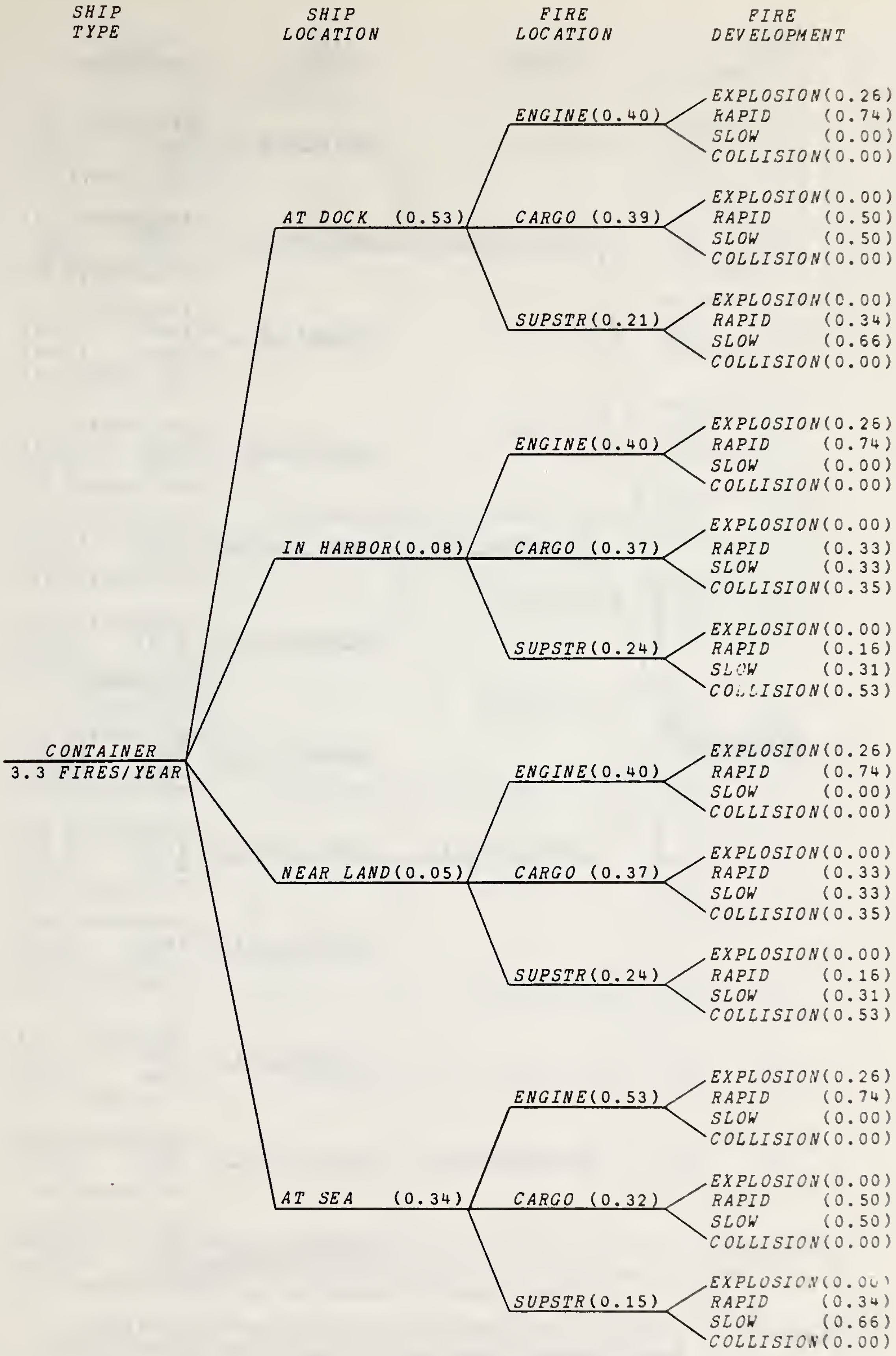


FIGURE VI-1 STATUS QUO, 1975: FREQUENCY OF FIRES BY SHIP TYPE AND CONDITIONAL PROBABILITIES (IN PARENTHESES) OF FIRES, BY SHIP LOCATION, FIRE LOCATION, AND FIRE DEVELOPMENT (CONTINUED)

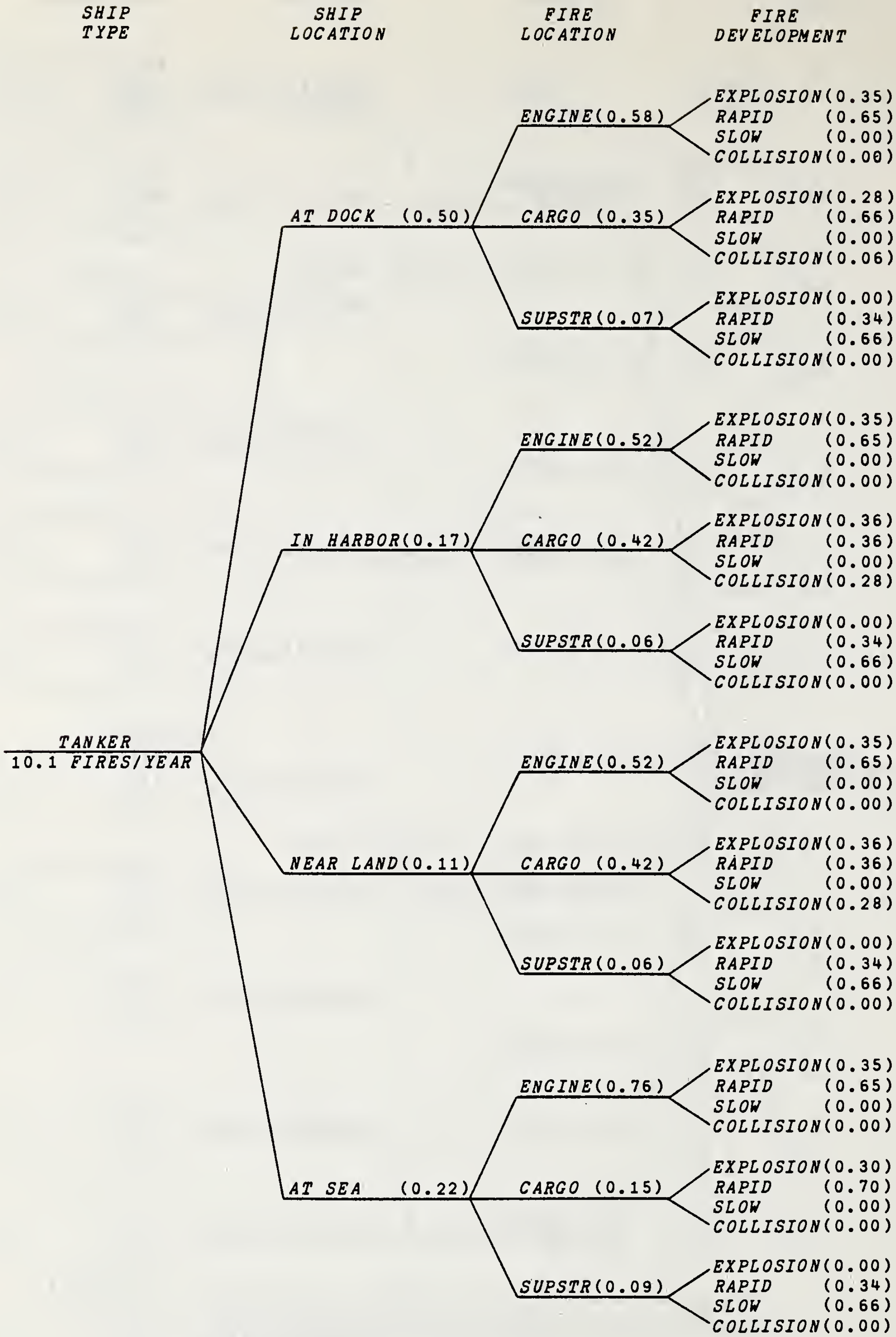


FIGURE VI-1 STATUS QUO, 1975: FREQUENCY OF FIRES BY SHIP TYPE AND CONDITIONAL PROBABILITIES (IN PARENTHESES) OF FIRES, BY SHIP LOCATION, FIRE LOCATION, AND FIRE DEVELOPMENT (CONTINUED)

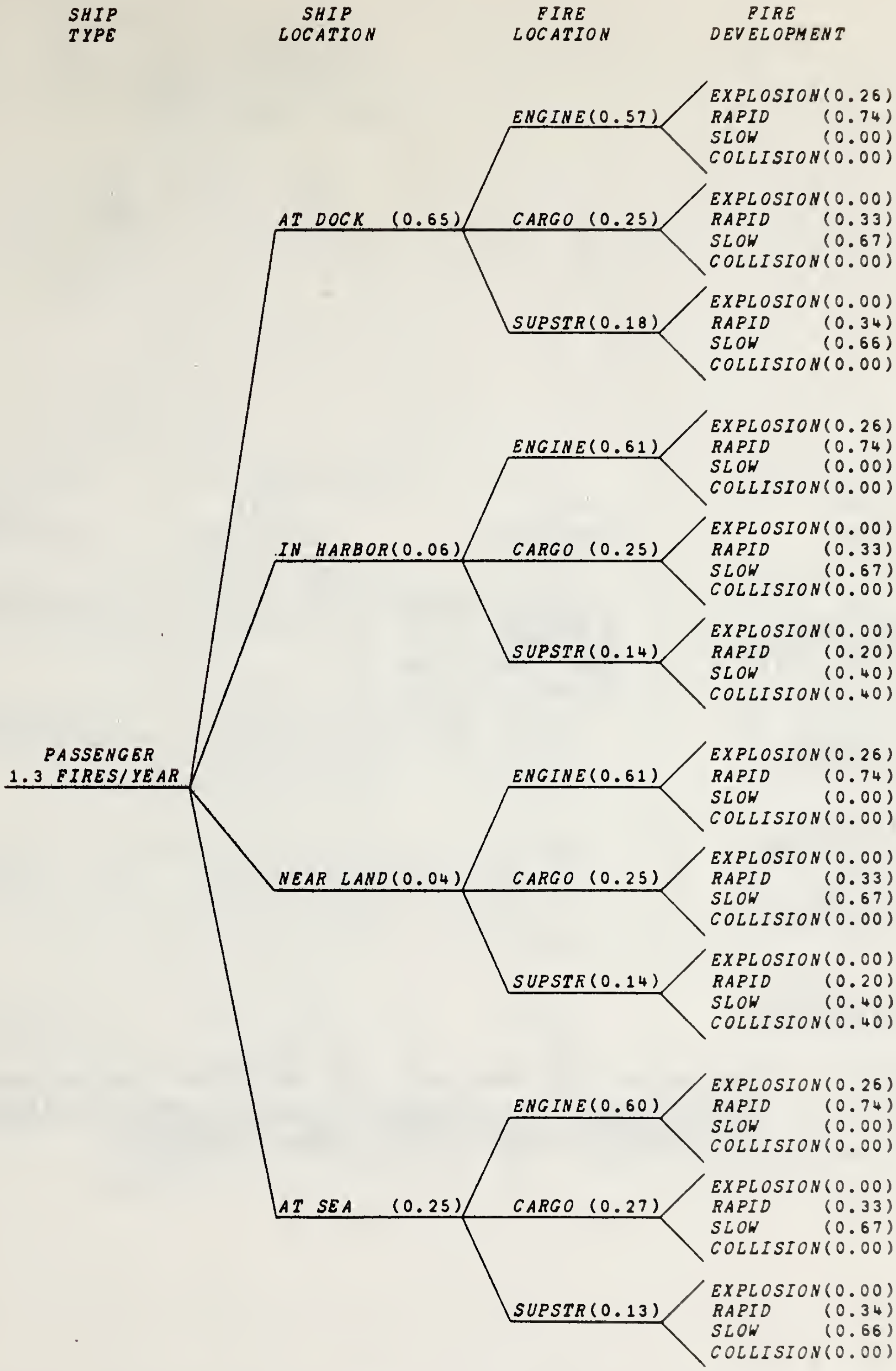


FIGURE VI-1 STATUS QUO, 1975: FREQUENCY OF FIRES BY SHIP TYPE AND CONDITIONAL PROBABILITIES (IN PARENTHESES) OF FIRES, BY SHIP LOCATION, FIRE LOCATION, AND FIRE DEVELOPMENT (CONTINUED)

SHIP TYPE	SHIP LOCATION	FIRE LOCATION	FIRE DEVELOPMENT
TANK BARGE 11.0 FIRES/YEAR	AT DOCK (0.51) IN HARBOR(0.15) NEAR LAND(0.14) AT SEA (0.20)		
CARGO BARGE 9.0 FIRES/YEAR			
FISHING BOAT 80.0 FIRES/YEAR			
TUG,TOW,UTILITY 50.0 FIRES/YEAR			
MISCELLANEOUS 34.0 FIRES/YEAR			

FIGURE VI-1 STATUS QUO, 1975: FREQUENCY OF FIRES BY SHIP TYPE AND CONDITIONAL PROBABILITIES(IN PARENTHESES) OF FIRES, BY SHIP LOCATION, FIRE LOCATION, AND FIRE DEVELOPMENT (CONTINUED)

SHIP TYPE	*SHIP SIZE*		*SHIP AGE*
FREIGHTER	<7500 *DWT*	(0.18)	0-5 *YR* (0.13)
	7500-15000 *DWT*	(0.52)	5-10 *YR*(0.16)
	>15000 *DWT*	(0.30)	>10 *YR* (0.71)
CONTAINER	<15000 *DWT*	(0.36)	0-5 *YR* (0.31)
	15000-21000 *DWT*	(0.34)	5-10 *YR*(0.39)
	21000-26000 *DWT*	(0.23)	>10 *YR* (0.30)
	>26000 *DWT*	(0.07)	
TANKER	<20000 *DWT*	(0.09)	0-5 *YR* (0.13)
	20000-50000 *DWT*	(0.52)	5-10 *YR*(0.15)
	50000-100000 *DWT*	(0.18)	>10 *YR* (0.72)
	>100000 *DWT*	(0.21)	
PASSENGER	<1000 *GT*	(0.60)	0-5 *YR* (0.14)
	1000-10000 *GT*	(0.25)	5-10 *YR*(0.09)
	>10000 *GT*	(0.15)	>10 *YR* (0.77)

FIGURE VI-2 STATUS QUO, 1975: PROBABILITIES (IN PARENTHESES) OF SIZE (IN DEADWEIGHT TONS OR GROSS TONS) AND AGE OF SHIPS ON WHICH FIRES OCCUR

Investigation casualty reports (1968-1976), and 6 years of American Hull Insurance Syndicate records of fire, explosion, and collision resulting in fire (1971-1976). These historical fire records provide most of the data required for the Fire Scenario Model. Where the data were sparse, informed judgment supplemented the historical records.

The criterion for an entry in our primary source, the Coast Guard records of fire and explosion, is that the incident caused more than $1,500 damage or resulted in either a death or in an injury incapacitating someone for at least 72 hours. The fact that smaller fires are not included in this list does not affect our study for the following reason: the total monetary loss, even if there are a large number of these fires, is small compared with the total monetary loss of larger fires. In addition, we have no reason to believe that there is any greater chance that such small fires would grow large enough to appear in the Coast Guard records in the future than they have in the past. We therefore do not include these small unreported fires.

Two comments should be made here to explain the adjustment made to the raw data when converting to the probability tree form required for the analysis. The frequency of fires aboard freighters was taken from the Coast Guard records for fiscal years 1973-1976, because previous years' records were influenced by fires on a large number of vessels built during World War II, most of which are no longer in service. Also, containership fire frequencies were obtained from fiscal years 1968-1976 because not until 1968 did these fires begin to appear.

In Figure VI-1, many probabilities found under Fire Development are listed as zero. This approximation was made to reduce the otherwise unmanageably large number of assessments to be made elsewhere in the model. The approximation is justified by the rare occurrence of the excluded fire developments and the fact that, for the specific fire location, the excluded level is closely approximated by one of those included.

Figure VI-1 also shows the probabilities of fire scenarios of collisions resulting in fires. The pattern of collision-induced fires is easily understood by realizing that these fires occur when the vessel struck is a tanker or tank barge. Thus, a dry cargo vessel at dock cannot experience this type of fire, but it can when under way in the harbor, should it ram a tanker or tank barge.

Finally, Table VI-1 completes the Fire Scenario Model for the status quo base case in 1975. It shows the percentage of ships equipped with built-in volume flooding extinguishing systems in the engine spaces and/or cargo spaces. For tanker cargo spaces, the suppression system is a fixed foam system. Each number in Table VI-1, determined from a 1976 survey furnished by the American Bureau of Shipping and our own telephone survey of the major shipping lines, may be interpreted as the probability that a built-in system is in place in the indicated fire location for the given ship type. Because we are interested only in

Table VI-1

STATUS QUO, 1975: PROBABILITY THAT THERE EXISTS A FIXED CO_2 OR HALON VOLUME FLOODING FIRE SUPPRESSION SYSTEM IN ENGINE ROOMS AND CARGO HOLDS, OR A FIXED FOAM SYSTEM ON TANKERS.

Ship Type	Ship Location	Engine Room	Cargo Space
Freighter	At dock, in harbor, or near land	0.90	0.65
	At sea	0.99	0.99
Container	At dock, in harbor, or near land	0.98	0.61
	At sea	0.99	0.60
Tanker	At dock, in harbor, or near land	0.91	0.71
	At sea	0.94	0.75
Passenger	At dock, in harbor, or near land	0.74	0.47
	At sea	0.99	0.99
Tank Barge		----	0.00

systems that are in place when a fire occurs, the statistics do not reflect the presence or absence of a system in cargo spaces of ore-carrying bulk carriers and the like. No such statistics were gathered, nor were they needed, for the smaller vessels. The different sets of probabilities for ships at dock versus ships at sea arise because different percentages of U.S. and foreign flag ships have built-in systems, and the foreign flag contribution is not included for fires at sea. The contribution from the U.S. and foreign flag ship built-in percentages at dock, in harbor, and near land are weighted by the fraction of fires in these locations on U.S. and foreign ships, as listed below:

Ship Type	% Fires U.S. Flag	% Fires Foreign Flag
Freighter	0.46	0.54
Container	0.89	0.11
Tanker	0.71	0.29
Passenger	0.47	0.53

This latter statistic was provided by the 14 years of Coast Guard ship fire records.

Given all the fire frequencies and conditional probabilities shown in Figures VI-1 and VI-2 and in Table VI-2, the relative likelihood of each fire scenario and the average number of fires per year for the 1975 base case can be computed.

Fire Scenario Data for the Status Quo Base Case, 1980-2000

The time horizon for this analysis of marine firefighting alternatives is 1980-2000. Consequently, the background or status quo base case for the Fire Scenario Model should update the data developed for the 1975 base case to take account of new trends and programs expected to occur over the next 20 years. These trends and programs are taking place independently of any of the marine firefighting alternatives described in this report; that is, they will take place regardless of which (if any) of the firefighting programs is enacted. For this reason, the trends and programs must be incorporated in the status quo or background case against which the alternatives are compared.

To account for the future trends in shipping, we used a study performed in 1976 by Temple, Barker, and Sloane of Wellesley Hills, Massachusetts. This study of ships that will be engaged in U.S. foreign trade over the next 20 years was provided by the Maritime Administration. Transportation specialists of the Maritime Administration indicated that this study was the best information it had available on this subject. Consequently, we used information from the

study to convert the 1975 base case of the Fire Scenario Model to its expected base case for the years 1980-2000.

The Temple, Barker, and Sloane study makes projections of the number of ships, the number of U.S. flag ships, and the size of ships that will be engaged in U.S. foreign trade from 1980-2000. The projections concern only cargo ships and only foreign trade, but the projections can be extended to include all ship types and U.S. domestic trade. Table VI-2 presents the factors derived from the Temple, Barker, and Sloane study, by which we multiplied the corresponding 1975 base case number of ships to obtain the 1980, 1985, 1990, 1995, and year 2000 prediction. In utilizing these factors, we made the following assumptions:

- o The number of ship fires expected to occur is proportional to the number of ships in service.
- o Because foreign and domestic shipping are interdependent, the growth of U.S. domestic shipping should parallel the growth of U.S. foreign shipping. For passenger ships, this reasoning is not compelling, but we adopt it as the best estimate available.

We therefore adapted the estimates for status quo, 1975 in the following manner: for freighter, container, and tankships, we used the relevant multipliers from Table VI-2. Fires at dock, in harbor and near land involve both U.S. and foreign flag vessels, and hence we used the figures for the total number of ships. At sea, only U.S. flagships in foreign trade are involved, so we used the figures for U.S. flag ships only.

Tank barges are relatively fixed in size; we therefore estimate that their number will grow with the amount of oil shipped and thus as the product of "number of ships" and "size of ships" for tankers in Table IV-2. Similarly, the number of cargo barges is estimated to grow as the product of "number of ships" and "size of ships" for freighters. For the service vessels, (tugboats, towboats, and miscellaneous) we estimate that the number of vessels will grow as "number of ships" for "total." Finally, we assume that the number of fishing boats will remain constant.

Another factor that will affect the base case in the future is the installation of radar-based, television-based, or computerized vessel traffic control systems. These systems reduce the number of collisions between vessels in the areas they cover. At present, such systems are in operation in the Houston Ship Channel, the Mississippi River below New Orleans, San Francisco Bay, Puget Sound, and Prince William Sound (Alaska); a similar system is to be installed for the port of New York by 1980.

Table VI-2

SHIP POPULATION, 1980-2000*

		1980	1985	1990	1995	2000
Freighter	Number of ships	1.14	1.19	1.25	1.22	1.29
	Number of U.S. flag ships	1.12	1.66	2.00	2.29	2.69
	Size of ships	1.16	1.28	1.44	1.60	1.75
Container	Number of ships	1.51	1.95	2.39	2.56	3.15
	Number of U.S. flag ships	1.53	2.11	2.59	2.74	3.14
	Size of ships	0.98	1.02	1.07	1.15	1.26
Tanker	Number of ships	1.09	1.02	0.94	0.89	0.88
	Number of U.S. flag ships	1.10	1.45	1.55	1.68	1.87
	Size of ships	1.12	1.46	1.60	1.67	1.78
Total	Number of ships	1.15	1.20	1.26	1.23	1.33
	Number of U.S. flag ships	1.23	1.74	2.07	2.30	2.65
	Size of ships	1.12	1.30	1.42	1.59	1.71

---

* The number of ships engaged in U.S. world trade is presented as a multiple of the number of ships engaged in this trade in 1975. The size of an average ship is also given relative to the base year 1975.

Because few of these systems were in operation during the years for which we have data, we had to estimate the effect of these systems on the expected number of ship fires during the years 1980-2000. Using Coast Guard statistics on the primary causes of collisions and Coast Guard and other estimates on the percentage reduction of collisions for each primary cause as a result of these vessel traffic control systems, we estimated a 40% reduction in collisions in the areas covered by vessel traffic control.

We estimated the same percentage reduction of collision-induced ship fires in areas covered by vessel traffic control systems. To estimate the percentage of collision-induced ship fires that occur in these areas, we noted that 28% (by tonnage) of the U.S. total shipping is in regions that are or will be covered by these systems; this figure agrees well with Coast Guard records of collisions involving tankers or tank barges in these regions. Combining the above figures, we estimated that 11% of collision-induced fires on tanker, freighter, container, and passenger ships in the 1975 base case will be eliminated in the years 1980-2000. Tank barge fires have the same origins as cargo fires on tankships. If the number of cargo fires from other causes is included, tank barge fires will be reduced by 1.6% because of the reduced number of collisions. Although these percentage reductions seem relatively small, it should be remembered that they affect the most costly ship fires.

For tankers, there is one other important program that will affect the base case in the future. This program is the recent agreement of the Intergovernmental Maritime Consultative Organization (IMCO) that almost all tankers of more than 20,000 Dwt. involved in international trade will have their cargo holds protected against explosions by inert gas systems. Specifically, all new crude oil carriers of 20,000 Dwt. or greater will have to be equipped with tank inerting systems when constructed. Existing crude oil carriers of greater than 70,000 Dwt. will have to be inerted by 1981, and existing crude oil carriers of 20,000-70,000 Dwt. will have to be inerted by 1983. Carriers of less than 20,000 Dwt. are exempted from these inerting requirements. Even in the absence of an international agreement, the U.S. Coast Guard will enforce these same standards for all U.S. flag tankers and all tankers entering U.S. ports and waters.

These inerting systems are reliable and will be routinely inspected; reliability estimates indicate that these systems will eliminate 95% of the explosions that would otherwise occur during loading, unloading, and tank-cleaning operations. However, some explosion dangers will be unaffected: 9% of the cargo tank fires on tankers occur on tankers smaller than those covered by the IMCO agreement, and 10% of the fires in tanker cargo holds occur during "hot work" repair in shipyards. On the basis of these estimates, the number of explosions expected to occur in the cargo holds of tankers will be reduced, for the period 1980-2000, to 31% (at dock) or 14% (in harbor, near land, and at sea) of the number given by the 1975 status quo data in Figure VI-1. It should be noted here, as above, that these

reductions affect the most costly ship fires.

All of these factors on number of vessels, vessel size, and tanker inerting were used to update the 1975 status quo Fire Scenario Model to represent the expected fire scenarios of the years 1980-2000. An indication of the changes involved is given by Table VI-3, which presents the frequencies of fires by ship type expected to occur over the next 20 years.

Other trends and programs that will affect the background case, such as the tankerman rating requirement, the establishment of four new maritime firefighting schools, and the growth of LNG shipping to U.S. ports, are incorporated in the Firefighting Performance Model. The trends described in this section are those that apply only to the Fire Scenario Model.

Table VI-3

STATUS QUO, 1980-2000: EXPECTED NUMBER OF SHIP FIRES (PER YEAR)

	1980	1985	1990	1995	2000
Freighter	25.4	29.7	32.9	34.4	38.1
Container	5.0	6.7	8.2	8.7	10.5
Tanker	10.1	10.4	10.0	9.9	10.3
Passenger	1.5	1.6	1.7	1.6	1.8
Tank barge	13.2	16.1	16.2	16.1	17.0
Cargo barge	11.9	13.7	16.2	17.6	20.3
Fishing boat	80.0	80.0	80.0	80.0	80.0
Tug, tow, utility	57.5	60.0	63.0	61.5	66.5
Miscellaneous	39.1	40.8	42.8	41.8	45.2

VII FIRE INVOLVEMENT AND DAMAGE MODEL

The Fire Scenario Model describes the setting in which the ship fire takes place and the manner in which it begins. The Fire Involvement and Damage Model furnishes a description of the extent of fire involvement, the degree of firefighting difficulty, and the amount of damage done to the ship, the cargo, the piers, and other land facilities nearby.

We constructed a model with 6 discrete levels of fire involvement and resulting damage. The possible fire involvement and resulting damage from ship fires span a continuous range, but the discrete levels were chosen to provide a consistent framework for assessing firefighting performance and for assessing monetary losses. The 6 discrete levels, shown in Tables VII-1, VII-2, and VII-3, span the range of fire involvement and resulting damage possible in ship fires.

The damage model was built jointly by SRI International and numerous marine industry and firefighting experts. The vessel damage segment, which is the heart of the model, was a joint effort of SRI and Morris Guralnick Associates, Naval Architects and Engineers, of San Francisco. The six levels of cargo, human, and waterfront damage were defined on the basis of data and expert judgment to be consistent with the vessel damage levels. The entire damage model was refined during numerous interviews with marine fire experts. Particularly useful modifications were suggested by the following five individuals: Captain Robert Hansen, Seattle Fire Department; Assistant Chief W. Donald Jeffrey, Airport Fire Department, Massachusetts Port Authority; Instructor Dale Krabbenschmidt, Military Sealift Command Firefighting School, Treasure Island, California; Deputy Chief Thomas Rush, Marine Division, New York City Fire Department; and Assistant Chief Robert Rose, San Francisco Fire Department.

The fire involvement and damage levels are constructed to fulfill simultaneously several purposes. First, the fire involvement levels must specify the extent, location, and nature of the fire. Second, the fire involvement levels must clearly indicate the ways in which the size of the fire, its heat and smoke, and the difficulty in gaining access impede firefighting efforts. Third, the damage levels must furnish a clear description of the damage done by the fire.

The six levels of fire involvement and resulting damage are used in two places in our model. First, after the fire scenario is established and the initial response of the crew is specified, we use these levels to specify the fire size and firefighting difficulty confronting the firefighters when they arrive and begin combatting the fire; this is the initial level of the fire. Firefighting may or may not contain the fire at this initial level; when the fire is extinguished, the final damage level (again, one of these six levels), describes the amount of damage

done. This damage is then converted to equivalent dollar loss in the Value Model (Chapter VIII).

Tables VII-1, VII-2, and VII-3 present the six levels of fire involvement and resulting damage. Levels 1, 2, 3, and 4 are specific to the fire location on the ship--engine (and machinery) space, cargo space, or superstructure; Levels 5 and 6 are the same for all fire locations because the fire at this level has engulfed at least the whole ship.

These descriptions specify property damage only. Human death and injury are taken into account for each damage level as determined by Coast Guard records (see Chapter II and Chapter VIII).

Table VII-1: FIRE INVOLVEMENT AND DAMAGE LEVELS FOR ENGINE ROOM FIRES

Level 1 -- Minor damage: local combustibles or some electrical cabling.

No difficulty in firefighting.

Does not stop ship operation.

Level 2 -- Local damage to some electrical and controlling devices for nonpropulsion systems.

Can be fought from within engine room.

Some difficulty keeping under way--perhaps resort to emergency systems.

Level 3 -- Widespread fire involvement causing extensive damage to susceptible electrical and mechanical equipment such as switchboards, the automatic control systems, or electric motors, and internal steel damage.

Flashover has occurred; dense heat and smoke; cannot be fought from within the compartment.

Possible recovery of propulsion afterwards.

Level 4 -- Massive engine room fire that ruins main condenser, piping, causes distortion of reduction gear and foundation, etc.; also causes buckling and warping of hull structure; some cargo in neighboring holds damaged.

Extreme heat and smoke; containment strategy only.

Must be towed to shipyard.

Level 5 -- Total loss of vessel and cargo because of total fire destruction or capsizing; damage to pier if at dock; possible congestion of channel if in harbor.

Vessel lost; strategy to protect waterfront.

Salvage.

Level 6 -- Port catastrophe: entire waterfront destroyed in catastrophic explosion and fire; many deaths and injuries (Texas City type of fire).

Table VII-2: FIRE INVOLVEMENT AND DAMAGE LEVELS FOR CARGO SPACE FIRES

Level 1 -- No ship damage; cargo damage only.
Freighter: minor flame or smoke damage in one deck.
Container: minor flame or smoke damage in one container.
Tanker: minor deck or vent fire.

May be difficult to gain access to seat of fire.

No effect on ship operation.

Level 2 -- Freighter: 25% of cargo in one deck involved in fire, causing damage to electrical cabling also.
Container: several containers involved.
Tanker: severe pump room fire or equivalent.

Smoke fills nonventilated area, making access more difficult.

Propulsion maintained.

Level 3 -- Freighter: full deck involved, mechanical equipment destroyed and damage to deck structure.
Container: 25 containers involved, plus damage to deck structure.
Tanker: one cargo tank destroyed.

Smoke and heat make access impossible; fought from outside the compartment.

Propulsion maintained.

Level 4 -- Freighter, Container: Entire cargo hold destroyed, warpage of hull-deck structure, damage to cargo in neighboring holds.
Tanker: several cargo tanks destroyed.

Extreme heat and smoke; containment strategy only.

Propulsion maintained or recovered afterward.

Level 5 -- Total loss (same description as for Level 5 engine room fire).

Level 6 -- Port catastrophe (same description as for Level 6 engine room fire).

Table VII-3: FIRE INVOLVEMENT AND DAMAGE LEVELS FOR SUPERSTRUCTURE FIRES

Level 1 -- One living compartment destroyed.

Firefighting difficulty comparable to fire in one room of dwelling.

No effect on ship operation.

Level 2 -- Galley or several compartments destroyed.

Firefighting difficulty comparable to similar fire in dwelling.

No effect on ship operation.

Level 3 -- Half of superstructure destroyed, not including bridge.

Fire spreads vertically with intense heat and smoke; fought from neighboring compartments.

Propulsion may be recovered later.

Level 4 -- Entire superstructure destroyed and damage to deck cargo sustained.

Containment strategy only.

All systems lost.

Level 5 -- Total loss (same description as for Level 5 engine room fire).

Level 6 -- Port catastrophe (same description as for Level 6 engine room fire).

VIII VALUE MODEL

The purpose of the Value Model is to convert each level of damage for each fire scenario to equivalent dollar loss. This conversion is required because all losses must be expressed in the same units for decision-making purposes.

One may ask why such a value model is constructed when the Coast Guard reports vessel, cargo, and 'other' losses for all ship fires included in the scope of this analysis. The reasons, as mentioned in Chapter II, are (1) the figures, even if accurate, do not include factors such as commercial losses from marine fire, (2) the Coast Guard's primary responsibility is determining the cause of the fire rather than the monetary value of the loss, (3) their preliminary estimates often may reflect accounting rather than economic data, and (4) many well-informed sources feel they cannot rely on the Coast Guard dollar loss figures. The need for an analysis that uses Coast Guard records only to establish fire scenarios and uses other sources to evaluate damages is clear.

The Value Model is composed of four submodels, one each for vessel damage, cargo damage, human damage, and waterfront and commercial damage. Each submodel converts its component of the marine fire loss to equivalent dollar loss in terms of constant 1975 dollars. The monetary loss for a ship fire is then the sum of the equivalent dollar losses each submodel provides for that particular fire scenario and damage level. The logic of each submodel is described below.

Vessel Value Submodel

The Vessel Value Submodel converts Levels 1, 2, 3, 4, and 5 vessel damage to equivalent dollar loss for each ship type. Level 5 damages are evaluated first since we begin by determining the value of the entire ship; Levels 4, 3, 2, and 1 then follow.

The valuation of the Level 5 total loss takes into account a ship's size and age and ship market conditions. We began the computation by obtaining the new replacement cost for each ship type and size specified in the Fire Scenario Model. These new replacement costs are is listed in Table VIII-1. These cost estimates were provided by Morris Guralnick Associates, Naval Architects and Engineers, San Francisco, and by the American Hull Insurance Syndicate. As specified in the Fire Scenario Model, the size categories are only as detailed as the analysis requires. In particular, very little detail is required to establish, to sufficient accuracy, the value of the small vessels listed near the bottom of Table VIII-1. It should be noted that the largest size

Table VIII-1

REPRESENTATIVE NEW REPLACEMENT COST FOR VESSEL TYPES
BY VESSEL SIZE IN DEADWEIGHT TONS, GROSS TONS, OR LENGTH

Ship Type	Ship Size	New Replacement Cost (dollars)
Freighter	< 7,500 Dwt.	$10,000,000
	7,500-15,000 Dwt.	19,000,000
	> 15,000 Dwt.	32,000,000
Container	< 15,000 Dwt.	22,000,000
	15,000-21,000 Dwt.	40,000,000
	21,000-26,000 Dwt.	60,000,000
	> 26,000 Dwt.	85,000,000
Tanker	< 20,000 Dwt.	9,000,000
	20,000-50,000 Dwt.	25,000,000
	50,000-100,000 Dwt.	35,000,000
	> 100,000 Dwt.	70,000,000
Passenger	< 1,000 Gt.	750,000
	1,000-10,000 Gt.	10,000,000
	> 10,000 Gt.	30,000,000
Tank barge	150 ft.	250,000
Cargo barge	150 ft.	200,000
Fishing boat	60 ft.	60,000
Tug, tow, utility	Average	800,000
Miscellaneous	—	440,000

category for freighters (> 15,000 Dwt.) contains a large number of bulk carriers, many in the 60,000 Dwt. class, with an average new replacement cost of $40,000,000.

Figure VI-2 in the Fire Scenario Model provides the fraction of fires by size category for each ship type. By multiplying the new replacement cost in Table VIII-1 by the fraction of fires for that size group, and summing over all sizes for a given type of ship, we produced the following size-averaged new replacement costs (averaged over size of ships on which fires have occurred).

Ship Type	Size-Averaged New Replacement Costs (dollars)
Freighter	$ 21,300,000
Container	41,300,000
Tanker	34,500,000
Passenger	7,500,000
Tank barge	250,000
Cargo barge	200,000
Fishing boat	60,000
Tug, tow, utility	800,000
Miscellaneous	440,000

These costs, in 1975 constant dollars, represent construction costs in a U.S. shipyard. These costs alone, however, are not sufficient for placing a value on total loss ship fires because older vessels are worth far less than their new replacement costs. What is needed is a method for determining the economic value of a ship as a function of its age.

From an economist's viewpoint, the value of a merchant vessel is the present value* of operating profits from its remaining years of service. What is needed is an expression relating a ship's value to its age, expected lifetime, and replacement cost. Under the assumption that each year of useful service life generates the same cash flow (in constant dollars), we developed the following depreciation formula expressing the value of a vessel as an age-dependent fraction of its new replacement cost: If a ship with an expected lifetime L is destroyed by fire when it is n years old, the loss is

* Present value is the amount that is currently equivalent at a given interest rate to a future payment or series of payments.

$$\{1 - [pv(n)/pv(L)]\}r ,$$

where r is the new replacement cost and pv(n) indicates present value of n years of operating profits.

Estimates of expected lifetimes for merchant vessels were provided by ship management specialists of the Maritime Administration:

Dry cargo vessels:	24 years
Tankships:	18 years

With the use of these lifetimes, the depreciation formula, and an interest rate (here set at 8%), the depreciation factor for each ship type was computed. In the computation of these depreciation factors, 1 year was added to the expected lifetime of the ships because salvage value approximates 1 additional year of service life.

In the Fire Scenario Model and here in the Value Model, we aggregated ship ages into three groups: less than 5 years old, between 5 and 10 years old, and greater than 10 years old. The average age for each of the 3 groups is weighted by the relative likelihood of ship fires for that group (provided in Figure VI-2). This weighted average produces the following depreciation factors, averaged by age of ships on which fires have occurred.

Vessel Type	Age-Averaged Depreciation Factor
Freighter, bulk carrier	0.28
Containership	0.45
Tanker	0.27
Passenger	0.26
Tug, fishing boat, barge, miscellaneous	0.40

These factors may be interpreted, for ships which have had fires, as the average fraction of new replacement cost. When multiplied by the new replacement cost, they yield average total loss values accounting for depreciation.

The final factor needed for placing a value on Level 5 total losses is the strength or weakness of the ship market. Experts at the American Hull Insurance Syndicate estimated that over the next 20 years, the ship market would be "soft" 60% of the time and "strong" 40% of the time. For each case, the table below shows the Hull Syndicate's estimates of this ship market effect. The numbers indicate market value as a fraction of new replacement cost.

Ship Type	Value Factor in Soft Market	Value Factor in Strong Market
Freighter	0.75	1.00
Container	0.75	1.00
Passenger	0.75	1.00
Tanker	0.50	1.20
Specialized vessel	1.00	1.00

These data reflect the more speculative nature of the demand for tankships. Weighting the multipliers by the probabilities of the soft and strong markets, we obtained the following expected market factors as a fraction of new replacement cost:

Vessel	Market Factor
Freighter, container, passenger	0.85
Tanker	0.78
Specialized vessel	1.00
Barge, fishing boat, tug	0.85

The figure for dry cargo vessels was assumed to hold for the smaller vessels, except for tank barges where the tanker figure was used.

The new replacement costs were then multiplied by the depreciation and market factors to produce the average dollar loss for vessel damage in total loss ship fires. This process of averaging over size, age, and market in Level 5 fires was performed to simplify the assessments of firefighting performance that come later.

The resulting Level 5 dollar losses for vessel damages are shown in Figure VIII-1. Note that this figure displays the entire set of equivalent dollar losses used in the Value Model. For each type of vessel, Figure VIII-1 shows vessel, cargo, waterfront, and commercial losses, and human deaths and injuries, for each fire level, each fire location, and each ship location.

With the use of the American Hull Insurance Syndicate data, which represent the "sound" value of a vessel at the time of loss, the Level 5

SHIP TYPE	FIRE LOCATION	FIRE LEVEL	VESSEL DAMAGE (K$)	CARGO DAMAGE (K$)	EXTERNAL DAMAGE AT DOCK (K$)	EXTERNAL DAMAGE IN HARBOR (K$)	DEATHS	INJURIES
		1	30	0	0	0	0.02	0.09
		2	312	0	0	0	0.09	0.45
	ENGINE	3	1,400	15	0	0	0.53	1.34
		4	3,800	102	0	0	0.80	2.67
		5	5,100	2,150	3,522	1,000	1.78	4.45
		1	0	7	0	0	0.01	0.01
		2	15	110	0	0	0.09	0.09
FREIGHTER	CARGO	3	200	273	0	0	0.36	0.36
		4	2,000	540	0	0	2.23	2.23
		5	5,100	2,150	3,522	1,000	10.69	8.91
		1	20	0	0	0	0.02	0.09
		2	130	0	0	0	0.18	0.36
	SUPERST	3	1,000	0	0	0	1.07	1.34
		4	3,400	64	0	0	1.60	1.78
		5	5,100	2,150	3,522	1,000	2.67	3.56
		1	30	0	0	0	0.02	0.09
		2	350	0	0	0	0.09	0.45
	ENGINE	3	1,700	30	0	0	0.53	1.34
		4	6,200	950	0	0	0.80	2.67
		5	15,800	15,250	2,596	1,000	1.78	4.45
		1	0	20	0	0	0.01	0.01
		2	25	150	0	0	0.09	0.09
CONTAINER	CARGO	3	260	950	0	0	0.36	0.36
		4	2,500	3,500	0	0	2.23	2.23
		5	15,800	15,250	2,596	1,000	10.69	8.91
		1	20	0	0	0	0.02	0.09
		2	160	0	0	0	0.18	0.36
	SUPERST	3	1,300	125	0	0	1.07	1.34
		4	5,000	1,060	0	0	1.60	1.78
		5	15,800	15,250	2,596	1,000	2.67	3.56
		1	30	0	0	0	0.02	0.03
		2	312	0	0	0	0.13	0.15
	ENGINE	3	1,700	0	0	0	0.45	0.49
		4	5,600	0	0	0	1.34	1.34
		5	7,300	890	10,820	1,400	3.83	3.83
		1	0	0	0	0	0.01	0.18
		2	75	7	0	0	0.27	0.53
TANKER	CARGO	3	900	135	0	0	0.71	0.80
		4	5,200	540	4,600	200	4.90	2.67
		5	7,300	1,800	10,820	1,400	12.25	4.46
		1	20	0	0	0	0.02	0.09
		2	130	0	0	0	0.18	0.36
	SUPERST	3	1,100	0	0	0	0.89	1.07
		4	4,100	0	0	0	1.25	1.43
		5	7,300	540	10,820	1,400	2.14	2.85
		1	9	0	0	0	0.02	0.09
		2	77	0	0	0	0.09	0.45
	ENGINE	3	400	0	0	0	0.53	1.34
		4	1,280	80	0	0	2.67	4.46
		5	1,650	1,540	2,310	490	5.35	6.24
		1	0	15	0	0	0.01	0.02
		2	5	75	0	0	0.09	0.18
PASSENGER	CARGO	3	40	290	0	0	0.27	0.36
		4	350	550	0	0	1.78	2.67
		5	1,650	1,540	2,310	490	4.46	4.46
		1	5	1	0	0	0.09	0.18
		2	50	5	0	0	0.45	0.89
	SUPERST	3	800	85	0	0	3.56	4.01
		4	1,380	130	0	0	6.24	6.68
		5	1,650	1,540	2,310	490	8.02	8.02

FIGURE VIII-1 VALUE MODEL RESULTS, BY SHIP TYPE AND FIRE LOCATION FOR EACH DAMAGE LEVEL

SHIP TYPE	FIRE LOCATION	FIRE LEVEL	VESSEL DAMAGE (K$)	CARGO DAMAGE (K$)	EXTERNAL DAMAGE AT DOCK (K$)	EXTERNAL DAMAGE IN HARBOR (K$)	DEATHS	INJURIES
TANK BARGE	CARGO	1	0	0	0	0	0.00	0.00
		2	20	1	0	0	0.00	0.00
		3	50	10	0	0	0.00	0.10
		4	200	40	300	0	0.30	0.70
		5	450	70	1,840	100	0.80	1.60
CARGO BARGE	CARGO	1	0	1	0	0	0.00	0.00
		2	0	5	0	0	0.00	0.00
		3	30	10	0	0	0.10	0.20
		4	50	30	0	0	0.40	0.80
		5	70	70	0	0	0.80	1.60
FISHING BOAT	ALL	1	1	0	0	0	0.00	0.00
		2	2	0	0	0	0.00	0.00
		3	7	0	0	0	0.00	0.10
		4	10	0	0	0	0.10	0.20
		5	20	0	0	0	0.20	0.40
TUGS, TOWS	ENGINE	1	30	0	0	0	0.02	0.04
		2	60	0	0	0	0.10	0.20
		3	150	0	0	0	0.40	0.70
		4	200	0	0	0	0.60	1.00
		5	270	0	0	0	0.67	1.00
	SUPERST	1	4	0	0	0	0.01	0.02
		2	11	0	0	0	0.02	0.04
		3	50	0	0	0	0.05	0.20
		4	140	0	0	0	0.10	0.30
		5	270	0	0	0	0.20	0.40
MISCELLANEOUS	ALL	1	8	0	0	0	0.00	0.00
		2	20	0	0	0	0.00	0.00
		3	40	0	0	0	0.00	0.00
		4	80	0	0	0	0.00	0.07
		5	150	0	0	0	0.03	0.40

NOTE: Figures are presented in thousands of 1975 dollars for vessel damage, cargo damage, and external (waterfront and commercial) damage; Level 6 damage is not shown. Human deaths and injuries are the average number per fire level, as obtained from Coast Guard records.

FIGURE VIII-1 VALUE MODEL RESULTS, BY SHIP TYPE AND FIRE LOCATION FOR EACH DAMAGE LEVEL (Continued)

vessel value was tested against specific loss data. The predictive ability of the model was found to be very good, and only minor calibration adjustments were needed. Experts in the Claims Department of the American Hull Insurance Syndicate agreed that the simple model was a good approximation of a rather complex market pricing mechanism. The model is also consistent with the United States Salvage Association's principal surveyor's comment that "a shipowner will not spend a lot of money to repair a vessel greater than 10 years old."

The next task in the Vessel Value Submodel is placing a value on Level 4 fire losses, which depend on fire location as well as ship type. The first step here was estimating the actual repair cost. If the repair cost is less than the ship's prefire value, the repair will be made and the Level 4 dollar loss is the repair cost. If the repair cost exceeds the ship's value even when so repaired, the repair will not be made and the ship will be sold for salvage. This latter case is called a "constructive total loss," and the Level 5 dollar loss is used for Level 4 damage because the ship is economically, even though not physically, a total loss. Finally, in some cases, the repair actually extends the useful life of the ship beyond its prefire remaining life. When this extension of life occurs, a credit must be subtracted from the repair cost to account for the excess over prefire worth.

The first of these steps, estimating Level 4 repair costs, was performed for each ship type and size by Morris Guralnick Associates, Naval Architects and Engineers, of San Francisco. The American Hull Insurance Syndicate provided its records of fire, explosion, and collision resulting in fire for the past 6 years, and the United States Salvage Association provided some general guidelines against which we could calibrate the Level 4 estimates and make the adjustments required to reproduce historical data.

Once the full repair costs for Level 4 engine, cargo, and superstructure fires for each ship type were determined, they were compared with Level 5 amounts for the different age groups, prior to taking the weighted average over ship age. As mentioned above, the smaller of either the repair cost or the depreciated ship value is used as the Level 4 dollar loss. The model predicts that Level 4 fires result in constructive total losses only in vessels greater than 10 years old, and then only in the following cases: engine room and superstructure fires in freighters and passenger ships, engine room and cargo space fires in tankers, and all Level 4 fires in small vessels.

Ship management experts of the Maritime Administration were consulted to determine when the repair of Level 4 damage extends the prefire life of a ship. For dry cargo vessels, superstructure and cargo repairs would not affect useful life, but engine room repairs would, on the average, add 2 years to an 8-year-old ship, thus changing its remaining life from 16 to 18 years, and 4 years to a 14-year-old ship, changing its remaining life from 10 to 14 years. For tankers, the decline in structural integrity of the bulkheads is the primary cause of

terminating useful life and no Level 4 fire repairs will correct this weakness. Finally, for passenger vessels, outdated passenger accommodations are the primary reason for ending life. Therefore, a new superstructure could add 8 years to the prefire remaining life of an 8-year-old ship and 5 years to a 14-year-old ship. None of the Level 4 fires would add to the prefire life of a ship that is less than 5 years old. Each of these additional extensions of service life beyond prefire expected lifetime is converted via the depreciation rule to a credit applied against the repair cost.

The smaller of repair cost or constructive total loss was then weighted by the probability of fire by age group to determine the average Level 4 dollar loss for each fire location and ship type. These Level 4 equivalent dollar losses are listed in the Level 4 rows of the vessel damage column of Figure VIII-1.

For Level 3 fires, the same procedure of obtaining a complete set of repair cost estimates from Morris Guralnick Associates and calibrating these estimates where possible against the American Hull Insurance Syndicate statistics of fires was followed. More Level 3 fires had occurred than Levels 4 or 5; therefore, more weight could be given here to the historical repair cost data. No Level 3 fire results in a constructive total loss except an engine room fire in a very old ship, where repair cost is approximately equal to ship value. The Level 3 dollar losses for each fire location and ship type are shown in Figure VIII-1.

The same procedure was carried out for Level 1 and Level 2 fires where repair cost is, to a first-order approximation, independent of ship age and ship size. Therefore, no complex weighting average scheme is required. The Level 1 and Level 2 dollar losses are shown in Figure VIII-1.

Cargo Value Submodel

The purpose of the Cargo Value Submodel is to establish the equivalent dollar loss to cargo for each level of damage for each fire scenario.

No centralized statistics are available in the United States on cargo loss from shipboard fire. The lack of any centralized data stems from the fact that any ship has cargoes from hundreds or even thousands of different parties; therefore, no one insurer or party is involved. Only a few of the major insurance carriers could provide data, but this data reflected a few individual incidents rather than cumulative losses. The companies could not distinguish cumulative fire and explosion cargo losses from the cargo claims they paid for all other fortuitous causes, including sinkings, strandings, collisions, sea water, and heavy weather. Consequently, a cargo damage submodel was built and made consistent with the 6 levels of fire involvement and damage for vessels.

Cargo claims experts of shipping lines estimated the expected amounts of cargo that would be damaged for each fire level, and these tonnages of average cargoes for the given ship type were converted to dollar losses. The model was then tested against specific cargo hold and cargo tank fires for which accurate loss data were available and calibrated to reproduce these historical data.

For dry cargo vessels, a 75% utilization rate, average for the U.S. shipping industry, was assumed. Cargo claims experts at Moore McCormack Lines and Lykes Bros. Lines were asked the question, "Given a 75% utilization rate in each deck of each hold, what percentage of the cargo in each deck would be damaged by fire, water, or smoke if a Level 3 fire burned in the upper 'tween deck and was extinguished with (a) water, or (b) CO_2?" The same question was asked for Level 3 fires in the lower 'tween deck and lower hold. Analogous sets of questions for Level 1, Level 2, Level 4, and Level 5 fires for each fire location were also asked.

To illustrate the kind of information required, we show in Figure VIII-2 the consensus responses for Level 3 fires in the cargo space of a break bulk freighter. The fire symbol indicates the deck involved and the numbers indicate the percentage of the cargo in that space and neighboring spaces that is destroyed by fire, smoke, or water.

Giving an equal likelihood to each of the three fires, we computed that the expected Level 3 cargo damage was equivalent to 69% of the cargo in an entire hold. An analogous damage portrait and set of computations was made for all damage levels for all fire locations of dry cargo vessels. All fire locations must be considered because a Level 4 engine room fire may singe or ignite cargoes in the neighboring hold, and a Level 4 superstructure fire may ignite or damage deck cargoes. The results of the damage model for dry cargo vessels are listed below, first for break bulk and then for containerized cargo.

<u>Cargo Hold Fires</u>

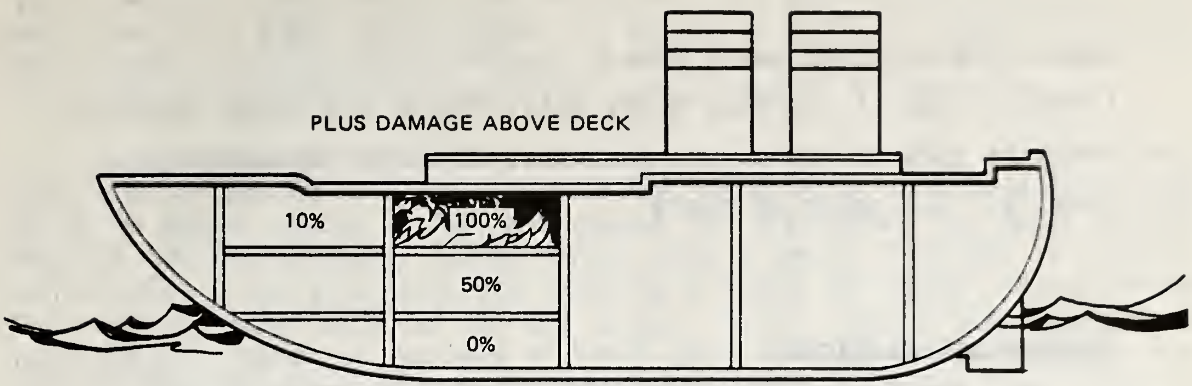
Level 1: 20 tons break bulk; 50% of one large (40 ft.) container

Level 2: 85% of one deck break bulk; 5 large containers

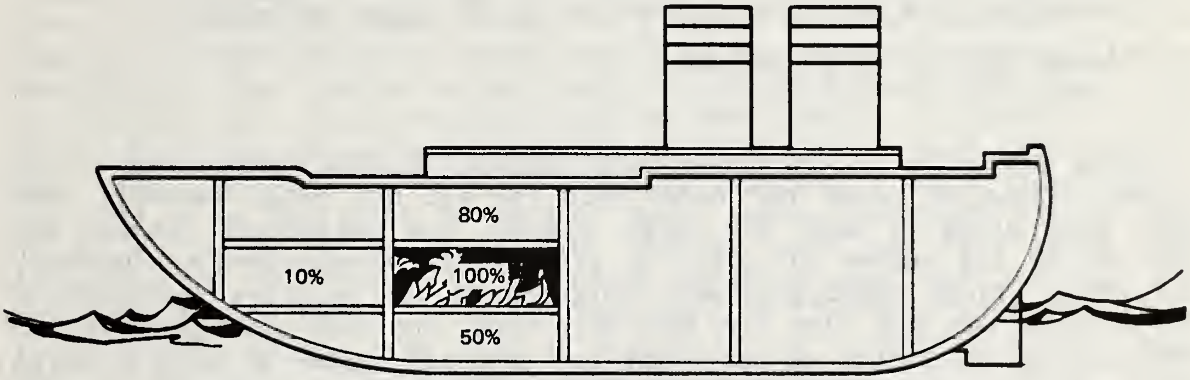
Level 3: 69% of one hold break bulk; 25 large containers

Level 4: 1.5 holds

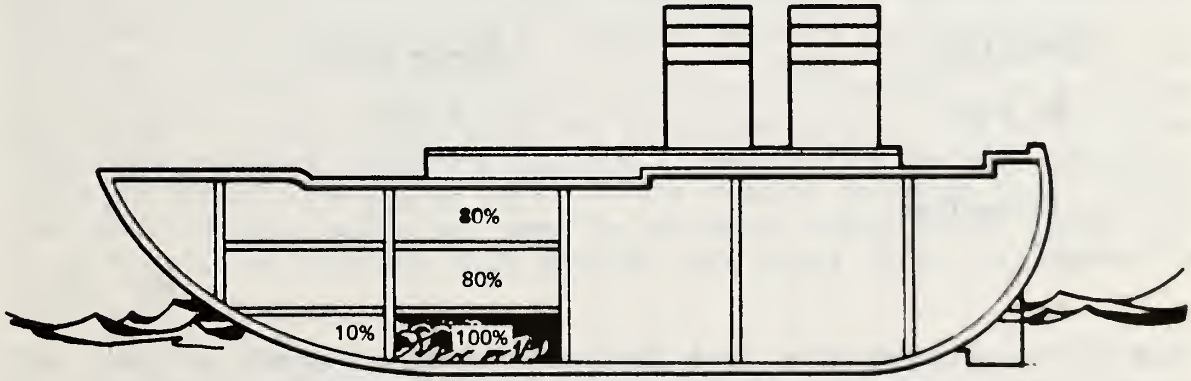
Level 5: All cargo on board



(1) UPPER 'TWEEN DECK



(2) LOWER 'TWEEN DECK



(3) LOWER HOLD

FIGURE VIII-2 CONSENSUS RESPONSES FOR THE AMOUNT OF CARGO DESTROYED IN VARIOUS LEVEL 3 FIRES IN THE CARGO HOLD OF A BREAK BULK FREIGHTER

Engine Room Fires

Levels 1 and 2: No cargo loss

Level 3: 10% of one deck break bulk; 75% of one large container

Level 4: 30% of one hold break bulk; 25 large containers

Level 5: All cargo on board

Superstructure Fires

Levels 1 and 2: No cargo loss

Level 3: 10% of one deck break bulk; 4 large containers

Level 4: 30% of one hold break bulk; 27 large containers

Level 5: All cargo on board

The next step in dry cargo loss analysis is the computation of the average value of cargo per cargo hold for all dry cargo vessels. For each size class of each dry cargo vessel, the deadweight tonnage was divided by the number of holds to provide the cargo-carrying capacity per hold. These capacities were weighted by the relative frequency of cargo fires per ship size for each ship type, and then multiplied by the 75% utilization factor to determine the expected number of tons of cargo per hold in which fires have occurred. The average value per ton of cargo by ship type was determined from U.S. Department of Commerce trade statistics and confirmed by port authorities of major ports and by steamship companies. These average cargo values are:

Cargo Type	Dollars/ton
Break bulk	$ 383
Bulk (dry)	46
Containerized	1,743
Tank	90

From these sets of data, the dry cargo damage description for each damage level can be converted to equivalent dollar loss, allowing a 10% credit for salvaging damaged cargo. This procedure was also carried out for cargo losses in passenger ships and cargo barges; all the equivalent dollar losses are listed in the cargo loss column of Figure VIII-1.

The model was then tested against a few specific large losses for which we have data known to be accurate. The predictive ability of the model was very good, as evidenced by the major Level 4 cargo fire aboard the 12,898 net ton containership SS C.V. Sea Witch, where claims for cargo damage against American Export Lines reached $10,430,000.

Tankship cargo losses are considerably less than dry cargo losses. This smaller amount of cargo loss is not surprising because most of the Level 4 and 5 tanker fires are caused by explosions in empty tanks. Even in collision-caused fires, often only a small fraction of the oil is spilled. The procedure for placing a value on tanker cargo losses followed the same logic as for dry cargo. First, damage descriptions in terms of the number of barrels or tanks were developed, the average size of the tank involved in fire or explosion was determined, and each of the damage levels was converted to dollar damages.

The Level 1 vent fire and Level 2 pump room fire were estimated to consume a maximum of 10 and 500 barrels, respectively. The Level 3 fire, destroying one cargo tank, was assumed to occur one-third of the time as an explosion in an empty tank with no damage to adjacent tanks, one-third of the time as an explosion in an empty tank that tears open an adjacent full tank, and one-third of the time as a collision either in a full or an empty tank resulting in an explosion that tears open a full tank. The Level 4 fire was similarly assumed to occur one-third of the time as an explosion in several empty tanks, one-third of the time as an explosion in an empty tank tearing open two full tanks, and one-third of the time as a collision breaking open and spilling the contents of four tanks. Finally, the Level 5 fire was assumed to occur three-fourths of the time from an explosion and one-fourth of the time from a collision. These explosions were estimated to occur in empty tankers 70% of the time, and in partially full tankers 30% of the time; the Level 5 collisions were estimated to occur in full tankers 80% of the time and in partially full tankers 20% of the time. Dividing net tonnage by the number of tanks, and then weighting by the probability of the Level 3 or higher fire by tankship size, we determined that the capacity of the average tank in which fire or explosion has occurred was 3,000 tons. Using the current crude oil price of $90/ton, we converted each level of cargo tank fire to the equivalent dollar loss shown in the cargo damage column of Figure VIII-1. Of engine room and superstructure fires on tankers, only the Level 5 fire results in cargo loss. Logic analogous to that above was used to estimate these dollar losses and those associated with the much smaller tank barge fires, also shown in Figure VIII-1.

Finally, cargo losses were estimated to be negligible in tugboat, towboat, work vessel, and fishing boat fires.

Human Value Submodel

The number of deaths and injuries from all ship fires in U.S. ports and waters and from U.S. flag ship fires everywhere is accurately recorded by the U.S. Coast Guard. We computed the expected number of deaths and injuries (injuries causing at least 72 hours of disability) for each level of damage for each fire location and ship type from Coast Guard records of fire, explosion, and collision resulting in fire. These figures are presented in Figure VIII-1. The expected number of deaths and injuries was then computed for all fire scenarios and a check was made to see that the model accurately reproduced the aggregate historical data.

Decisions regarding the level of expenditure for safety--or, in general, any decision that considers both dollar expenditures and a chance of death--are aided by introducing the concept of the value of life. The value of life in the present context is the amount of resources society would be willing to allocate to avoid one human death resulting from ship fire.

It should be emphasized that this value of life is not intended to reflect the amount that society might be willing to pay to avoid the certain death of an identified individual. Nor is it intended to reflect the value of a human life in some catastrophic event in which many human lives are lost. In both of these cases, society may well have special preferences. When it comes to low levels of danger for a fairly large group of people, however, it is obvious that there is some limit to the resources that society is willing to allocate to decrease the level of danger.

It is not a simple task to find this value of life (Howard, 1978; Howard, Matheson, and Owen, 1978). In practice, there is a value of life that can be inferred from government decision making, even though there may not have been much conscious thought about a particular dollar value of life when the decisions were made. The value of life implicit in government decisions ranges from $140,000, used in the cost-benefit analysis of highways (Linnerooth), to $5,000,000 implicit in the proposed criteria for light water reactor radiation waste systems (Nuclear Regulatory Commission, 1975). For the base case, we adopted figures commonly used in policy analyses of this type: $300,000 per death and $30,000 per disabling injury (U.S. Department of Transportation, 1975).

Waterfront and Commercial Value Submodel

The purpose of the Waterfront and Commercial Value Submodel is to convert waterfront and commercial damages resulting from ship fires to equivalent dollar loss. These waterfront and commercial damages range from minor flame damage to a berth to the Texas City type of port catastrophe that we call a Level 6 fire. The Waterfront and Commercial

Value Submodel includes both physical damage to waterfront facilities and the economic losses resulting from disruption of commerce. Specifically, the following ship-related and pier-related losses are taken into consideration:

<u>Ship-Related</u>

(1) Lost revenue while vessel is undergoing repair.
(2) Unemployment of crew.
(3) Cost of raising vessel if capsized or sunk and obstructing traffic.

<u>Pier-Related</u>

(1) Destruction of berth, transit shed, cargo on pier, etc.
(2) Cost of fighting the fire.
(3) Cost of pollution clean-up.
(4) Loss of commerce in port area and shortage of critical supplies.
(5) Unemployment of longshoremen.
(6) Death and injury of shoreside personnel.

<u>Major Port Catastrophe</u>

(1) All pier-related costs listed above, plus destruction of marine, industrial, and commercial waterfront facilities.
(2) Major loss of life and injury from fire, explosion, or the release of noxious gases.
(3) All ship-related costs listed above, plus damage to other ships, piers, and bridges.
(4) Major long-term disruption of commerce in area.
(5) Resulting unemployment of marine and other personnel.

The point of view taken in this analysis is that only net losses to society are to be included. An important implication of this societal net loss concept is that a loss to one operator may not be a net loss to society. For example, if a shipowner has a vessel temporarily out of service while in a repair yard, his lost freight revenues are not a net loss to society if another operator transports his cargoes and receives the freight revenues. Similarly, if one berth is temporarily out of service and another berth nearby handles all the displaced traffic, there is no net disruption of commerce even though the single operator may suffer.

In lengthy discussions with shipping line officers and with representatives of port authorities in major U.S. ports, we were assured

that the average utilization of ships and pier facilities was low enough that the loss of a single ship or a single berth would practically never result in any net disruption of commerce. In most ports, not even the loss of several berths would result in a net disruption of commerce. There are, however, a few specific unique ships and berths which, if rendered inoperative, would cause disruption, and these cases are accounted for in our model. Thus, an operator's lost revenues from an inoperative ship or berth are not, in most cases, included as a net societal loss; disruption of commerce is a net loss to society only in the case of the unique facility or the Level 6 port catastrophe where a major section of the waterfront is destroyed. Physical damage to all real property (vessel, cargo, human, and waterfront), on the other hand, is always included in the model.

The fire scenarios in which waterfront and/or commercial damage can occur are:

- Level 5 freighter fires at dockside and in harbor.
- Level 5 containership fires at dockside and in harbor.
- Level 4 tanker cargo fires and Level 5 tanker fires (all fire locations) at dockside and in harbor.
- Level 5 passenger ship fires at dockside and in harbor.
- Level 4 tank barge fires at dockside and Level 5 tank barge fires at dockside and in harbor.
- Level 6 fires.

Lower level fires on merchant vessels, all fires at sea, and all fires on tugs, cargo barges, and fishing boats do not result in waterfront or commercial damage serious enough to be included in the model. The computations for waterfront and commercial losses from Level 5 freighter and tanker fires at dockside are described in the following paragraphs. Similar logic was used for waterfront and commercial damage for the other relevant Level 4 and 5 fires.

The probability tree for the freighter Level 5 fire at dock (Figure VIII-3) shows that if there is no explosion, there is a 10% chance of destroying the berth, the transit shed, and its cargo, and a 90% chance of only minor berth damage. An explosion doubles the chance of destroying the berth and transit shed. Representatives of the Port Authority of New York and New Jersey, the New Orleans Port Commission, Moore McCormack Lines, and Lykes Bros. Lines provided data to help estimate the dollar damages associated with both major and minor berth damage. In the case of major damage, the general cargo berth damage was estimated at $5 million, the transit shed damage at $4 million, and the cargo damage at $2.5 million; minor berth damage on the lower branch was estimated at $600,000.

There is also a 10% chance that the berth is unique or in a nearly 100% utilization area, causing a disruption of commerce. Before repairing or rebuilding the unique berth that suffered major damage, approximately 490,000 tons of cargo that would otherwise have entered

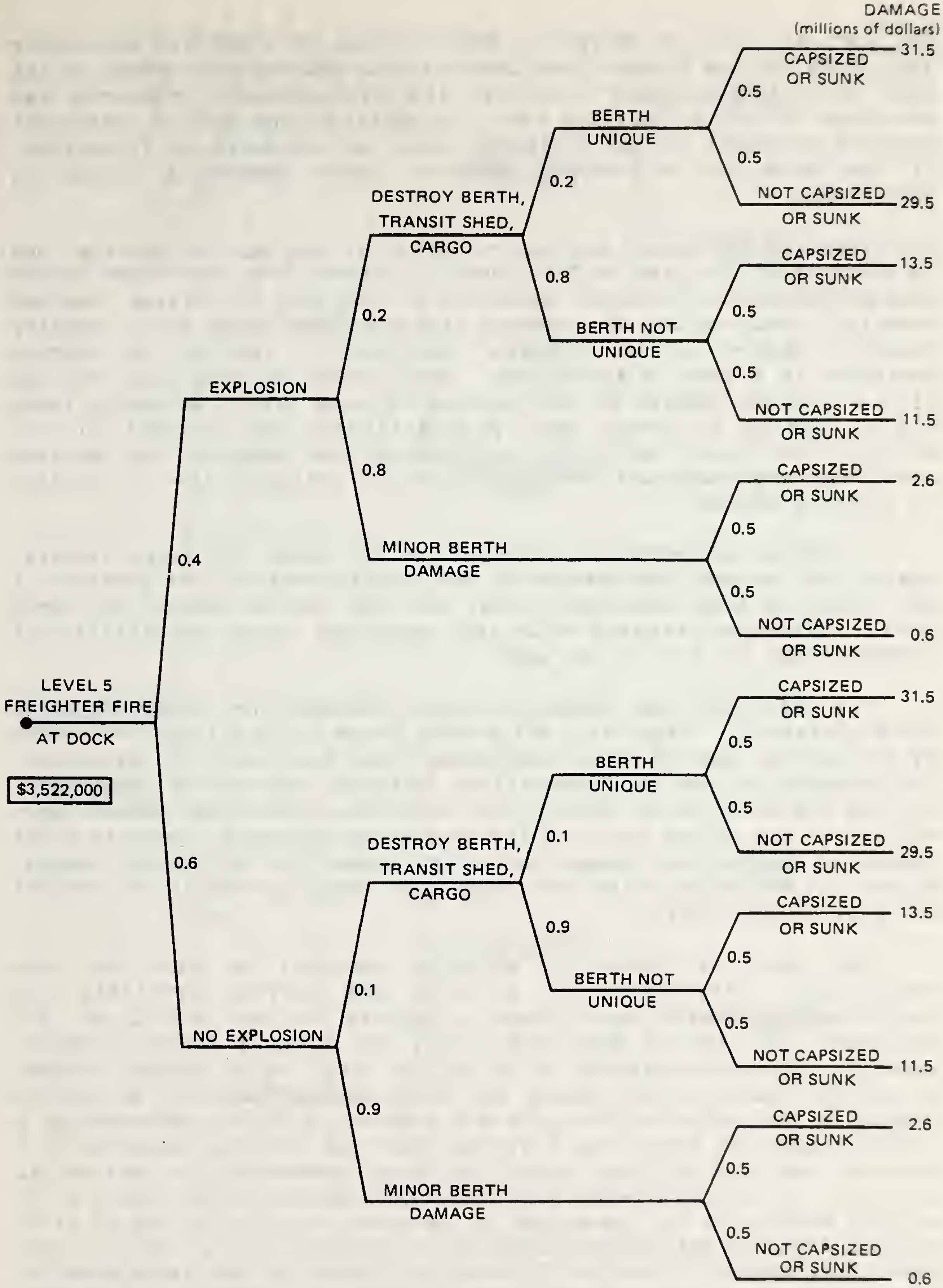


FIGURE VIII-3 PROBABILITY TREE TO EVALUATE THE WATERFRONT AND COMMERCIAL DAMAGE RESULTING FROM A LEVEL 5 FREIGHTER FIRE AT DOCK

the port will not be shipped. With the use of a $35/ton multiplier derived by the New Orleans Port Commission as the economic effect on the area in a longshoremen's strike, the disruption of commerce was estimated to be a $17 million loss. In addition, the cost of additional overland transport of the displaced cargo was estimated at $1 million. If the berth is not unique, none of these commercial losses is significant.

Finally, the vessel must be raised if it has sunk or capsized and is obstructing the pier or the channel. Experts from the United States Salvage Association provided estimates of the cost of raising capsized vessels. Their estimates, together with data from Coast Guard casualty reports, enabled us to determine the cost of raising the average freighter at a dock as $2,000,000. The probability tree shows the sum of the relevant damages at the endpoint of each path. Weighting these dollar losses by their path probabilities (the product of all probabilities along the path) and summing, we computed the expected waterfront and commercial loss from a Level 5 freighter fire at dockside to be $3.52 million.

A similar procedure was carried out for other dry cargo vessels, taking into account the absence of the transit shed but the presence of the crane on most container piers, and the smaller amount of cargo aboard passenger vessels with the resulting lower probability of communicating the fire to the pier.

The Waterfront and Commercial Value Submodel for tanker fires is quite different. Practically all docked tanker Level 5 fires are caused by explosions, some of these explosions being the result of collisions. The probability tree in Figure VIII-4 indicates that 98% of these Level 5 fires are expected to result from explosions (sometimes induced by a collision) and 2% are not. In the case of an explosion, there is a 90% chance of major pier damage and a 10% chance of only minor damage. Without an explosion, major and minor pier damage probabilities are 40% and 60%, respectively.

The level of damage is strongly dependent on wind and tide conditions. Key personnel at Arco and Chevron terminals and well-documented Coast Guard casualty reports for the M/V Elias, S/T Corinthos, and the SS Sansinena fires, all Level 5 tanker fires at dockside, provided estimates of the dollar loss. Major damage includes $3 million damage to the piping and cargo loading facility, $2 million damage to the concrete structure and bumpers, $375,000 representing a 1-in-20 chance of destroying a storage tank and contents valued at $7.5 million, and $1.5 million damage to nearby commercial or residential property. If a unique berth sustained major damage, an additional $7.05 million represents the disruption of commerce; this is the sum of $4.05 million from a 10% volume loss in a refinery for a 270-day pier rebuilding period (figured at 75 cents per barrel as the value added to the product by the refinery), $2 million for more costly overland

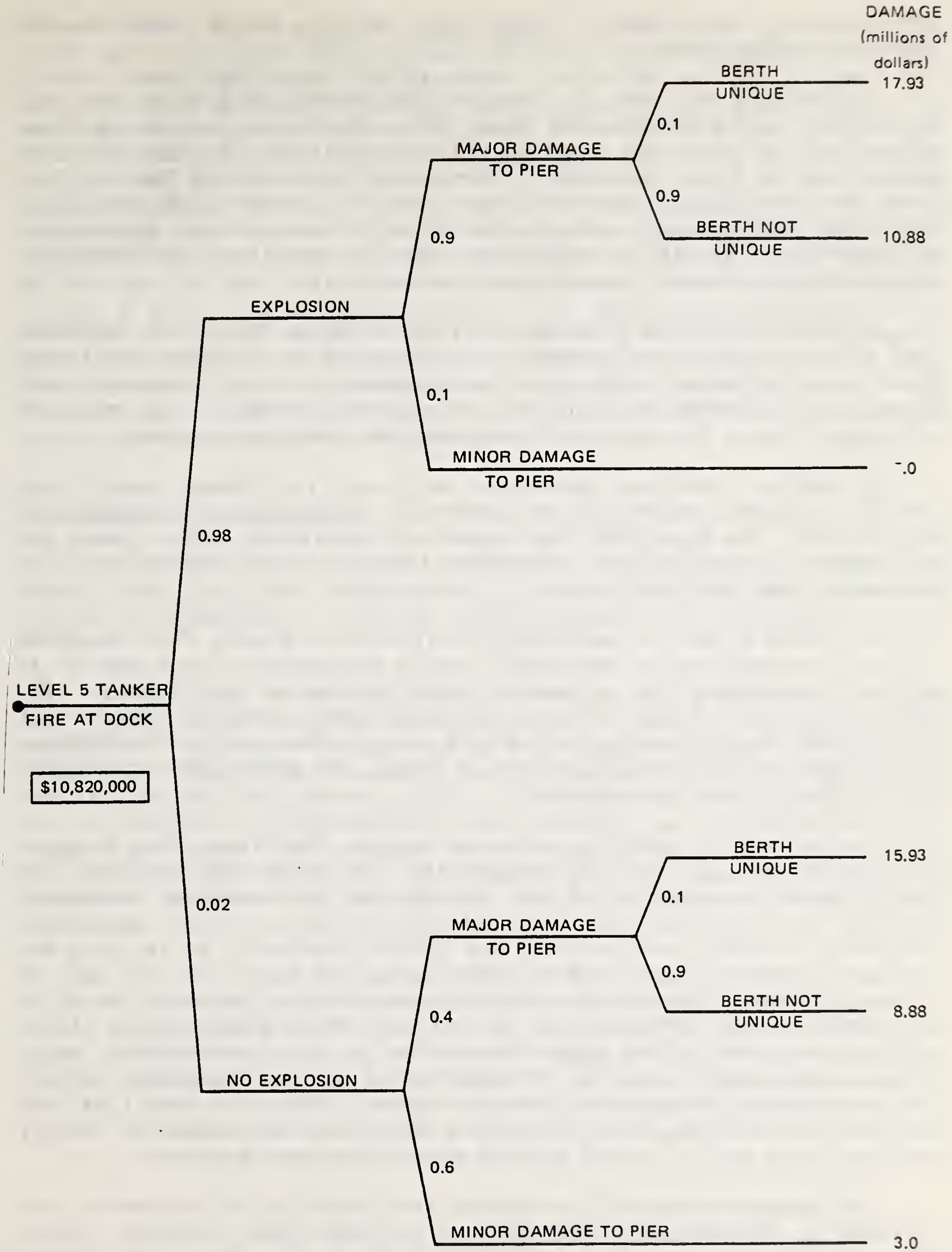


FIGURE VIII-4 PROBABILITY TREE TO EVALUATE THE WATERFRONT AND COMMERCIAL DAMAGE RESULTING FROM A LEVEL 5 TANKER FIRE AT DOCK

transport to cover some of the lost supply, and $1 million for short-term unemployment.

Further, in the case of explosion, the vessel is sunk and the cost of raising the vessel averages $2 million. Whether or not an explosion occurs, the pollution and clean-up adds an additional $2 million to each Level 5 tanker fire at dockside. The probability tree in Figure VIII-4 shows the sum of the relevant losses at the endpoint of each path. Weighting these dollar losses by their path probabilities, we computed an expected $10.82 million equivalent loss for waterfront and commercial damages from the Level 5 tanker fire at dockside.

Because this Level 5 tanker fire at dockside is a very important part of the marine fire problem on an expected value basis, we tested these loss estimates with great care against the SS Sansinena, M/V Elias, and S/T Corinthos fires and our experts' judgments. An excellent agreement between the model and the historical data was achieved.

A similar modeling procedure was used for other tanker fire scenarios causing waterfront or commercial losses, as well as for tank barge fires. The waterfront and commercial equivalent dollar losses for all damage levels for all ships are listed in the fourth and fifth columns of Figure VIII-1.

The Level 6 port catastrophe fire differs so greatly from the Level 5 fire in probability of occurrence and in magnitude of loss that it is analyzed separately as a special case throughout the model. The probability that a Level 5 fire will develop into a Level 6 fire or that a fire will occur initially at Level 6 is analyzed in the Firefighting Performance Model. Here, in the Value Model, the equivalent dollar loss of the Level 6 fire is discussed.

In the Level 6 fire, for which we use the 1947 Texas City disaster as a prototype, all marine, industrial, and commercial buildings and facilities in the vicinity of the ship are heavily damaged or destroyed. Hundreds of lives are lost and hundreds of injuries are sustained. Obviously, the ship and its cargo are totally destroyed, as is the pier, and heavy damage is sustained by nearby ships and piers. In the case of a Level 6 tanker fire at a refinery, much of the property described above would not be present, but the refinery and storage complex itself would be destroyed. This major destruction in the waterfront area would cause a long-term disruption of commerce during the rebuilding period. One other scenario that could lead to a Level 6 loss is a ship fire that emits a toxic cloud that is carried by the wind through a heavily populated area and kills and injures several thousand people.

The damage descriptions above are intended to represent our conception of the Level 6 fire. As mentioned earlier, these descriptions are based on the Texas City fire in which the French freighter Grandcamp and the American freighter Highflyer, both loaded with ammonium nitrate, exploded and devastated the industrial waterfront

area. Frank Rushbrook, in Fire Aboard, claimed that property damage from the Texas City fire reached $67 million. Given the currently greater knowledge about the explosive properties of Class A materials and the tightly enforced regulations on shipping munitions and explosives in ports, experts in port authorities around the country believe that the physical damage in the Texas City fire was on the high end of the distribution of currently possible Level 6 fire damage. However, taking into account the effect on the economy, the effect of inflation, and the value of life, we estimate the equivalent dollar loss of a Level 6 fire today at around $1 billion. Clearly, this figure is an average representing a less severe but still disastrous $500 million fire, as well as a $2 billion fire. The $1 billion estimate is not intended in any way to be a careful prediction, but rather an attempt to take into account the possibility of a catastrophic fire as much as 50 times greater than the average Level 5 tanker fire at dockside. The sensitivity of all of our results to this billion-dollar estimate is shown wherever the results are presented.

Value Model: 1980-2000

In the period 1980-2000, two factors will alter the Value Model above, which has been constructed to reflect the base year 1975. (It should be remembered that all dollar amounts are expressed in 1975 dollars.)

As explained in the Fire Scenario Model, the size of the vessels and their cargo-carrying capacity will change during the period 1980-2000. Estimates for the increase in size are given in Table VI-2, where the average size of vessels for the period 1980-2000 is given as a multiple of the 1975 average size. These figures are given explicitly for freighters, containerships, and tankers; we estimated that the figures given for the averaged "total" will apply to passenger ships, and that the smaller classes of vessels will not change in average size over this period. The changes in the Value Model are made in the following way:

- Vessel Value Submodel, 1980-2000. To account for the increasing size of vessels, we approximated the ship value as being proportional to its size over the limited range involved. Hence, the only change to the Vessel Value Submodel for the years 1980-2000 is the multiplication of Level 5 vessel damage values for freighter, container, tanker, and passenger ships by the appropriate entries under "size of ships" in Table VI-2.

- Cargo Value Submodel, 1980-2000. The cargo damage for Level 1 and 2 fires is essentially independent of the capacity of the cargo holds, whereas cargo damage resulting from Level 3, 4, and 5 fires depends on the amount of cargo in the hold. Hence, the change to the

Cargo Value Submodel for the years 1980-2000 is accomplished by multiplying the Level 3, 4, and 5 cargo damage values for freighter, container, tanker, and passenger ships by the appropriate entry for "size of ships" in Table VI-2.

IX FIREFIGHTING PERFORMANCE MODEL

The Firefighting Performance Model describes the process of fire detection and suppression for each possible fire emanating from the Fire Scenario Model. It is the Firefighting Performance Model that is principally affected by most of the alternatives we consider; for instance, additional training for firefighters improves their effectiveness and hence reduces, in most cases, the amount of damage done by the fire.

To assess the differential impact of alternative firefighting programs, we must measure in the Firefighting Performance Model the reduction in fire damage (relative to the status quo) resulting from having better trained firefighters and/or better equipment. The Firefighting Performance Model must, therefore, take into account for each fire scenario the initial response of the crew; the size of the fire when organized firefighting efforts begin; the degree of marine firefighting expertise, if any, of the leader of the firefighting team; the level of marine firefighting training, if any, of the firefighters themselves; the availability of built-in suppression systems and other equipment; and ultimately, the extent of damage when the fire is extinguished.

For each type of merchant vessel and for tank barges, a computerized firefighting model has been constructed to measure the effectiveness of each firefighting program for each fire scenario. For tugs, tows, fishing boats, cargo barges, and other smaller vessels, an elaborate performance model was not developed; these smaller vessels are much simpler, and the level of firefighting expertise and specialized training have a much smaller impact here than in fires aboard merchant ships. For these smaller vessels, the impact of each alternative was assessed directly by firefighting experts.

In this chapter, we first define the elements of the Firefighting Performance Model developed for merchant ships, discuss the interdependence of these elements, and then present the probability assessments for these elements and the procedure for obtaining them. We then describe the quantification of firefighting effectiveness in terms of reduced damage levels, and finally the process for calibrating the entire model to reproduce the status quo base case.

Elements of the Firefighting Performance Model

The elements of the Firefighting Performance Model must be constucted in such a way that professional firefighting experts can readily estimate the effectiveness of the firefighting effort.

Initial Response of Crew

Ship fires are usually discovered by crew members, but sometimes by night relief personnel or stevedores when the ship is in port. The initial response of those who discover the fire can be either "good" or "bad" as defined below:

- Good. The essential "first-aid" procedures are performed: the fire department and/or ship officers are notified; fuel pumps and ventilation fans are shut off; fire doors are closed, etc.
- Bad. One or more of the above steps is omitted with the result that the fire is allowed to spread easily during the period before the organized firefighting force arrives on the scene.

Initial Level of Fire

To measure the impact of a firefighting team or piece of equipment, it is necessary to know the amount of damage that had already occurred when fire suppression began and the extent of damage when the fire was extinguished. The initial level of the fire is defined to be one of the 6 levels of the Fire Involvement and Damage Model that, for each ship fire, best describes the size of that fire and the degree of firefighting difficulty it presents at the time fire suppression activities begin. In most ship fires, firefighting begins when fires are at the low levels of involvement, but in a few fire scenarios, the initial fire level is one of the high levels.

Expertise in Firefighting Leadership

The level of expertise in marine firefighting of the leaders of the firefighting team is divided into several categories, depending on whether the fire is being fought by land-based or ship-based forces.

For land-based forces:

- No expertise in marine firefighting on the part of the fire department chief or captain who is the commanding officer at the fire. Such a captain or chief has all the knowledge and ability necessary to fight dwelling and

structural fires, but is not well acquainted with the complex layout of large ships, nor is he well versed in specialized techniques for fighting ship fires.

- o Expertise in marine firefighting. The fire department chief or captain in command of the fire (or a trusted advisor) has a good grasp of the basic aspects of ship construction and design, nautical terminology, the existence and deployment of built-in fire suppression systems, and of the special techniques useful in fighting ship fires. He also has some understanding of ship stability and is fully aware of the danger of capsizing the ship by indiscriminate application of large quantities of water. Finally, he has available a store of specialized agent and equipment specifically gathered for fighting ship fires.

- o Special Seattle Plan type of expertise in fighting ship fires. The fire department officer in command of the fire has detailed knowledge, usually through a trusted advisor, of ship layout and design, is quite familiar with nautical terminology and with the reading of cargo manifests, and is able to use the built-in suppression systems. He has at his disposal a detailed prefire plan of the ship, which his advisor may well have prepared himself. Finally, he also has a store of specialized equipment that has been gathered specifically for use in fighting ship fires.

For ship-based forces:

- o No expertise. The ship officer who leads the firefighting effort has had no recent experience or practical training in firefighting.

- o Expertise. The ship officer has recently had experience or training in firefighting that can effectively contribute to firefighting strategy and leadership.

Skills of Firefighters

In a similar way, the skills of the firefighters are divided into several categories.

For land-based forces:

- o No training. The firefighters have no experience or practical training that gives them familiarity with the layout of a ship and the passageways and ladders providing access to the engine, cargo, and superstructure spaces.

- o Training. The firefighters have had recent experience or a low level of practical training that gives them some familiarity with nautical terminology, the interior of ships, access routes, and the most important difficulties and dangers encountered in fighting a ship fire.

For ship-based forces:

- o No training. The ship's crew has had no recent experience or training in extinguishing a large fire.
- o Training. The ship's crew (at least a firefighting squad) has had recent experience in the laying of hoses and the application of agent, and has acquired some confidence (or psychological preparedness) in its ability to fight a large fire.

Built-in System

Because a built-in CO_2 or halon volume flooding system can make a tremendous difference in many types of ship fires, we have explicitly included this element in our model. Similarly, we have included the effect of large foam systems installed on some tankers. The critical question is whether such systems are used correctly.

- o Yes. The space in which the fire occurs has in place a built-in system that is in working order and is properly supplied with agent; the ship officer or fire department commanding officer chooses to use this system; he or his assistants operate the system correctly; in the case of CO_2 or halon volume flooding systems, he does so only after sealing off the ventilation to the space, and he does not reopen the space too early.
- o No. Any one of the above conditions is not met, and the built-in system does not extinguish the fire.

Interdependence of Elements of the Model

To keep the number of assessments small enough so that proper care and attention can be given to every assessment, only the important interdependencies are taken into account. Thus, rather than make separate assessments for every possible combination of elements of the Fire Scenario and Firefighting Performance Models, we identified the instances where the specification of one element in the model significantly affects the assessment of another. Only in these instances is a unique set of conditional probability assessments required.

The important dependencies affecting firefighting performance are discussed below; the examples given are not intended to be an exhaustive list, but rather a sample to illustrate some of the more important considerations necessary for the assessments of firefighting performance.

Initial Crew Response

The initial response of the crew depends on ship type (level of crew training varies), ship location (crew may be absent in port), fire location on ship (response varies by compartment), and fire development (explosions and collisions are more likely to cause panic and confusion).

Initial Level of Fire Involvement

The initial level of fire involvement depends on ship type (cargoes differ); ship location (cargo holds may be open at dock, collisions almost always occur in harbor); fire location aboard ship (access routes to fire and characteristics of fire vary); fire development (explosion may spread fire rapidly); and initial response of crew (a bad response allows the fire to spread more rapidly).

Firefighting Leadership and Skills of Firefighters

The firefighting leadership and the skills of the firefighters depend on ship location (land-based forces at dock and ship-based forces at sea) and on the ship type (officers and crews on tankers and passenger ships are more conscious of fire and are often better trained in firefighting).

Correct Use of Built-in System

Finally, the probability that the built-in system is used correctly depends on the ship type (the percentage of spaces with systems in place varies by ship type), ship location (land-based forces sometimes choose not to use these systems), fire location (the cargo hold system is harder to deploy than the engine room system), and the expertise and training of the firefighters (built-in systems are often used incorrectly).

Although this list is only a partial list, it gives an idea of the important dependencies that must explicitly be taken into account when assessing firefighting performance.

Assessment of Probabilities for the Status Quo, 1975

The assessment of probabilities is more difficult in the Firefighting Performance Model than it is for the Fire Scenario Model because there is less data available. To obtain the probability that the initial response of the crew is good or bad or the probability that the initial size of the fire is Level 1, 2, 3, 4, or 5, we relied heavily on marine casualty reports, on incidents recounted to us by firefighting experts in the fire departments of major U.S. ports and in the safety and damage control departments of major shipping lines, and on the experience of instructors in marine firefighting schools. A major constraint is imposed on these probabilities by the requirement that the model must reproduce the spectrum of final levels of damage that are derived from the Coast Guard records; this procedure is discussed later in this chapter.

Probabilities of Initial Crew Response and Initial Level of Fire Involvement

The values finally adopted for the probabilities specifying the initial response of the crew and the initial level of fire involvement are presented in Figure IX-1. For each possible combination of ship type, ship location, fire location, and fire development, the probability for a good or bad response is presented in parentheses; given the good or bad initial response, the remaining figures on each line give the probability that the initial size of the fire is Level 1, 2, 3, 4, or 5. For example, given an explosion in the engine room of a freighter at dock, the probability of a good crew response is 0.4. Given this good response, there is a 48% chance that the firefighters will find a Level 1 fire when they arrive; there is a 47% chance they will find a Level 2 fire, and a 5% chance they will find a Level 3 fire. Entries with dashes occur when no assessment is necessary because the fire scenario does not occur, as discussed in the Fire Scenario Model.

Several general comments may help elucidate the general structure of Figure IX-1. The initial response of the crew is best at sea and worst at dock. This difference reflects considerations such as that the fire at dock or in harbor may be discovered by a stevedore or a night watchman unfamiliar with the ship or by a foreign crew member unfamiliar with the method of summoning the fire department. In addition, there is understandably a greater temptation to abandon the ship when it is at dock or in harbor than when it is at sea.

Initial levels of the fire display a more complicated pattern. Land-based firefighting forces take longer to get to fires in harbor than to fires at the dock because the firefighting forces must be transported by fireboats (or the ship must be brought to the dock). Hence, the initial levels of fire involvement are higher for the fires aboard ships in harbor than for fires aboard ships at dock. Ship-based

SHIP LOCATION	FIRE LOCATION	FIRE DEVELOPMENT	INITIAL RESPONSE	INITIAL FIRE LEVEL 1	2	3	4	5
AT DOCK	ENGINE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	EXPLOSION	GOOD (0.40)	0.48	0.47	0.05	0.00	0.00
			BAD (0.60)	0.32	0.57	0.11	0.00	0.00
		RAPID	GOOD (0.50)	0.81	0.19	0.00	0.00	0.00
			BAD (0.50)	0.68	0.27	0.05	0.00	0.00
		SLOW	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	SUPERSTRUCTURE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	EXPLOSION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD (0.30)	0.60	0.40	0.00	0.00	0.00
			BAD (0.70)	0.35	0.65	0.00	0.00	0.00
		SLOW	GOOD (0.40)	0.80	0.20	0.00	0.00	0.00
			BAD (0.60)	0.55	0.45	0.00	0.00	0.00
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	CARGO (FREIGHTER, PASSENGER)	EXPLOSION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD (0.45)	0.48	0.50	0.02	0.00	0.00
			BAD (0.55)	0.20	0.70	0.10	0.00	0.00
		SLOW	GOOD (0.50)	0.75	0.25	0.00	0.00	0.00
			BAD (0.50)	0.40	0.60	0.00	0.00	0.00
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	CARGO (CONTAINER)	EXPLOSION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD (0.45)	0.90	0.08	0.02	0.00	0.00
			BAD (0.55)	0.75	0.22	0.03	0.00	0.00
		SLOW	GOOD (0.50)	0.95	0.05	0.00	0.00	0.00
			BAD (0.50)	0.85	0.15	0.00	0.00	0.00
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	CARGO (TANKER)	EXPLOSION	GOOD (0.20)	0.00	0.00	0.56	0.22	0.22
			BAD (0.80)	0.00	0.00	0.56	0.22	0.22
		RAPID	GOOD (0.60)	0.55	0.45	0.00	0.00	0.00
			BAD (0.40)	0.40	0.50	0.10	0.00	0.00
		SLOW	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		COLLISION	GOOD (0.20)	0.00	0.00	0.20	0.80	0.00
			BAD (0.80)	0.00	0.00	0.20	0.80	0.00
	CARGO (TANK BARGE)	ALL	ALL	0.32	0.35	0.21	0.07	0.05

FIGURE IX-1 STATUS QUO, 1975: PROBABILITY (IN PARENTHESES) FOR GOOD OR BAD INITIAL RESPONSE OF THE CREW TO A FIRE, AND GIVEN THAT RESPONSE, THE PROBABILITY OF THE INITIAL FIRE LEVEL

SHIP LOCATION	FIRE LOCATION	FIRE DEVELOPMENT	INITIAL RESPONSE	INITIAL FIRE LEVEL 1	2	3	4	5
IN HARBOR NEAR LAND	ENGINE (FREIGHTER,CONTAINER, TANKER,PASSENGER)	EXPLOSION	GOOD(0.40)	0.48	0.31	0.20	0.00	0.00
			BAD (0.60)	0.32	0.39	0.29	0.00	0.00
		RAPID	GOOD(0.60)	0.81	0.13	0.06	0.00	0.00
			BAD (0.40)	0.68	0.18	0.14	0.00	0.00
		SLOW	GOOD(--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		COLLISION	GOOD(--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	SUPERSTRUCTURE (FREIGHTER,CONTAINER, TANKER,PASSENGER	EXPLOSION	GOOD(--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD(0.50)	0.45	0.55	0.00	0.00	0.00
			BAD (0.50)	0.25	0.75	0.00	0.00	0.00
		SLOW	GOOD(0.60)	0.65	0.35	0.00	0.00	0.00
			BAD (0.40)	0.45	0.55	0.00	0.00	0.00
		COLLISION	GOOD(0.20)	0.00	0.00	0.33	0.67	0.00
			BAD (0.80)	0.00	0.00	0.33	0.67	0.00
	CARGO (FREIGHTER,PASSENGER)	EXPLOSION	GOOD(--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD(0.50)	0.35	0.58	0.07	0.00	0.00
			BAD (0.50)	0.15	0.70	0.15	0.00	0.00
		SLOW	GOOD(0.60)	0.60	0.40	0.00	0.00	0.00
			BAD (0.40)	0.35	0.65	0.00	0.00	0.00
		COLLISION	GOOD(0.20)	0.00	0.00	0.33	0.67	0.00
			BAD (0.80)	0.00	0.00	0.33	0.67	0.00
	CARGO (CONTAINER)	EXPLOSION	GOOD(--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD(0.50)	0.75	0.20	0.05	0.00	0.00
			BAD (0.50)	0.60	0.33	0.07	0.00	0.00
		SLOW	GOOD(0.60)	0.90	0.10	0.00	0.00	0.00
			BAD (0.40)	0.80	0.20	0.00	0.00	0.00
		COLLISION	GOOD(0.20)	0.00	0.00	0.33	0.67	0.00
			BAD (0.80)	0.00	0.00	0.33	0.67	0.00
	CARGO (TANKER)	EXPLOSION	GOOD(0.30)	0.00	0.00	0.56	0.22	0.22
			BAD (0.70)	0.00	0.00	0.56	0.22	0.22
		RAPID	GOOD(0.50)	0.55	0.45	0.00	0.00	0.00
			BAD (0.50)	0.40	0.50	0.10	0.00	0.00
		SLOW	GOOD(--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		COLLISION	GOOD(0.20)	0.00	0.00	0.20	0.80	0.00
			BAD (0.80)	0.00	0.00	0.20	0.80	0.00
	CARGO (TANK BARGE)	ALL	ALL	0.24	0.24	0.18	0.32	0.02

FIGURE IX-1 STATUS QUO, 1975: PROBABILITY(IN PARENTHESES) FOR GOOD OR BAD INITIAL RESPONSE OF THE CREW TO A FIRE, AND GIVEN THAT RESPONSE, THE PROBABILITY OF THE INITIAL FIRE LEVEL (CONTINUED)

SHIP LOCATION	FIRE LOCATION	FIRE DEVELOPMENT	INITIAL RESPONSE	INITIAL FIRE LEVEL 1	2	3	4	5
AT SEA	ENGINE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	EXPLOSION	GOOD (0.50)	0.48	0.47	0.05	0.00	0.00
			BAD (0.50)	0.32	0.57	0.11	0.00	0.00
		RAPID	GOOD (0.65)	0.81	0.19	0.00	0.00	0.00
			BAD (0.35)	0.68	0.27	0.05	0.00	0.00
		SLOW	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	SUPERSTRUCTURE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	EXPLOSION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD (0.60)	0.75	0.25	0.00	0.00	0.00
			BAD (0.40)	0.40	0.60	0.00	0.00	0.00
		SLOW	GOOD (0.70)	0.90	0.10	0.00	0.00	0.00
			BAD (0.30)	0.70	0.30	0.00	0.00	0.00
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	CARGO (FREIGHTER, PASSENGER)	EXPLOSION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD (0.60)	0.60	0.40	0.00	0.00	0.00
			BAD (0.40)	0.35	0.65	0.00	0.00	0.00
		SLOW	GOOD (0.70)	0.80	0.20	0.00	0.00	0.00
			BAD (0.30)	0.50	0.50	0.00	0.00	0.00
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	CARGO (CONTAINER)	EXPLOSION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		RAPID	GOOD (0.60)	0.90	0.10	0.00	0.00	0.00
			BAD (0.40)	0.75	0.25	0.00	0.00	0.00
		SLOW	GOOD (0.70)	0.95	0.05	0.00	0.00	0.00
			BAD (0.30)	0.85	0.15	0.00	0.00	0.00
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	CARGO (TANKER)	EXPLOSION	GOOD (0.40)	0.00	0.00	0.56	0.22	0.22
			BAD (0.60)	0.00	0.00	0.56	0.22	0.22
		RAPID	GOOD (0.70)	0.55	0.45	0.00	0.00	0.00
			BAD (0.30)	0.40	0.50	0.10	0.00	0.00
		SLOW	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
		COLLISION	GOOD (--)	--	--	--	--	--
			BAD (--)	--	--	--	--	--
	CARGO (TANK BARGE)	ALL	ALL	0.35	0.32	0.17	0.11	0.05

FIGURE IX-1 STATUS QUO, 1975: PROBABILITY (IN PARENTHESES) FOR GOOD OR BAD INITIAL RESPONSE OF THE CREW TO A FIRE, AND GIVEN THAT RESPONSE, THE PROBABILITY OF THE INITIAL FIRE LEVEL (CONTINUED)

forces tend to fight a fire at sea as soon as possible, whereas they may wait for assistance from land if they are near land.

Probabilities of Expertise in Firefighting Leadership and Skills of Firefighters

Assessment of the probabilities of expertise in firefighting leadership and of the skills of the firefighters must be done separately for land-based forces and for ship-based forces. For land-based forces, we either visited or telephoned municipal fire departments and/or port authority fire departments in the following 30 U.S. port cities. These 30 cities include every port area through which passes at least 1% of total tonnage shipped in domestic and foreign trade. These cities and the smaller ports in their immediate vicinity with which their fire departments have mutual aid agreements, make up 83% of the tonnage of all U.S. maritime trade. The 30 port cities and the smaller ports in their immediate vicinities are listed below in a geographical ordering.

Portland, Me.
Boston, Ma.
New York, N.Y.
Elizabeth, N.J. and Jersey City, Hoboken, Bayonne, and Newark
Philadelphia, Pa. and Marcus Hook, Camden, Gloucester and Paulsboro
Baltimore, Md.
Norfolk, Va. and Newport News
Jacksonville, Fl.
Tampa, Fl.
Mobile, Al.
New Orleans, La.
Baton Rouge, La.
St. Louis, Mo.
Duluth, Mn.
Chicago, Il.
Toledo, Oh.
Detroit, Mi.
Cleveland, Oh.
Houston, Tx.
Galveston, Tx. and Texas City
Port Arthur, Tx. and Beaumont
Corpus Christi, Tx.
Long Beach, Ca.
San Francisco, Ca., Oakland and Richmond
Portland, Or.
Seattle, Wa., Tacoma, and other Puget Sound ports

Anchorage, Ak.
Honolulu, Hi.

This survey enabled us to establish the level of marine firefighting expertise among the municipal and/or port commission fire department chiefs and captains in these ports, as well as the level of ship familiarity of their firefighters. In ports where expertise and/or training do exist, we went into greater detail, as exemplified in the sample probability tree in Figure IX-2. For each port area, probabilities were assessed for each branch, and at the end of each path, assessments were made of the probability of finding expertise or training in that particular set of circumstances. The analysis takes into account the fact that some major port areas cover several different municipalities with fire departments of varying levels of expertise and training. Similarly, because of the size and configuration of the waterfront in many cities, and of arrangements between municipal and port authority fire departments, it may not always be the companies with marine expertise and training that fight the fire. Finally, in areas where only a few people have marine expertise and training, they may be off duty and unavailable when the ship fire occurs. These figures are averaged over all U.S. port areas (weighted by tonnage) and are presented in Figure IX-3.

It should be emphasized that marine firefighting expertise and training involve considerable time and must be renewed regularly. Because a major ship fire is an infrequent occurrence even in the busiest ports, the results presented in Figure IX-3 should not be taken as a criticism of municipal fire departments that may have small budgets and other urgent needs. One of the primary purposes of this report is to ascertain the level of loss to be expected from the rare but costly event of a ship fire and the level of resources that should be allocated to training or equipment for combating these fires.

In the case of ship-based forces, we took into account data obtained from marine firefighting schools, maritime unions, merchant marine academies, and major shipping lines to estimate the probability of finding a ship officer with firefighting expertise and/or a squad of crewmen with firefighting training or experience aboard a ship. This probability varies with ship type, because, for example, U.S. regulations require a tankerman's certificate for certain ratings aboard tankers. Similarly, passenger vessels have officers and crew who are generally more conscious of fire and who are required to have frequent drills. It should be remembered that, at sea, only U.S. flag ships are included. These estimates are also presented in Figure IX-3.

Correct Use of Built-in System

Finally, the probability that the built-in system is used correctly must be determined. This assessment was one of the most controversial in the entire study. At first, we asked marine fire experts in shipping

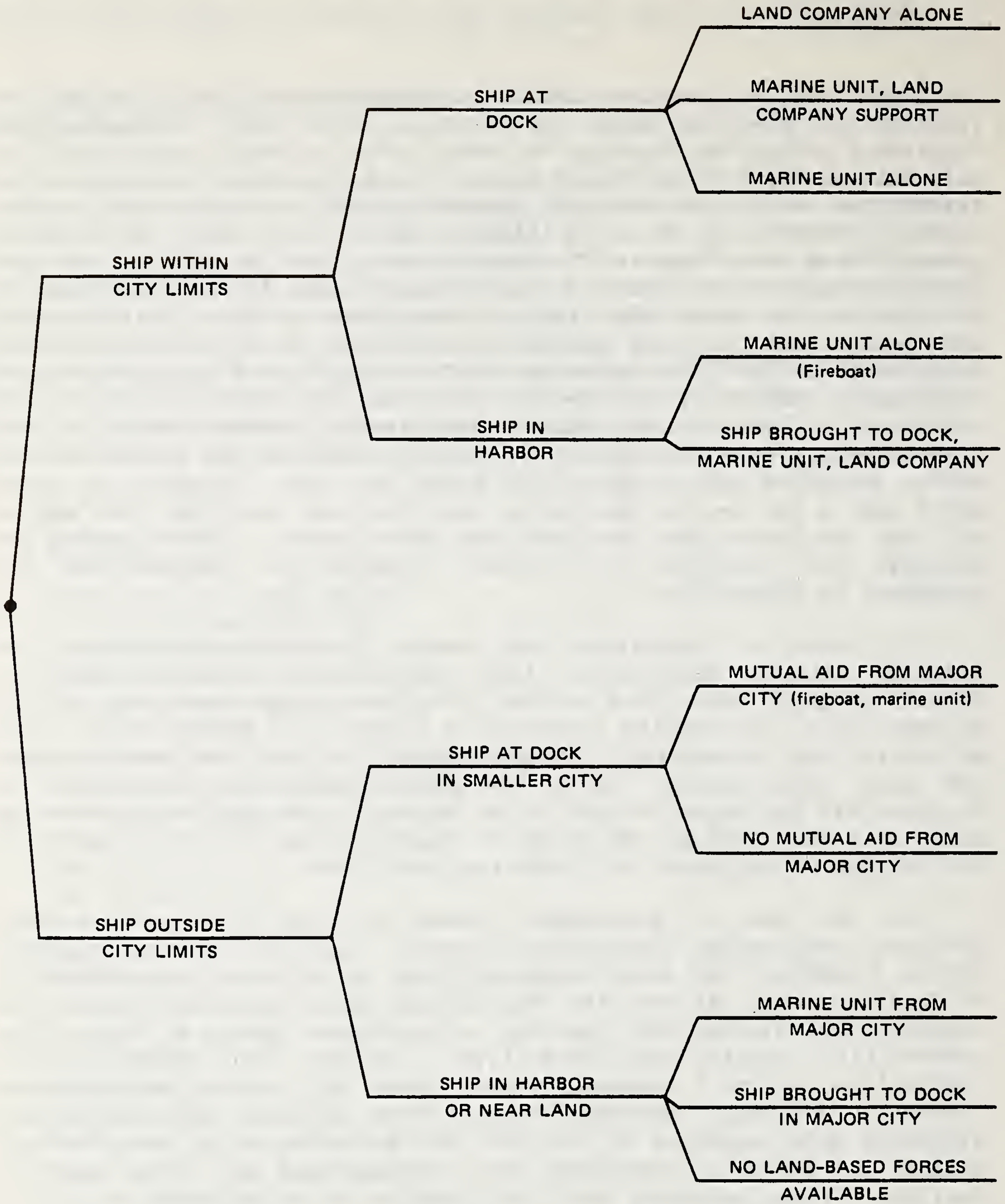


FIGURE IX-2 SAMPLE PROBABILITY TREE FOR ESTIMATING THE EFFECTIVE LEVEL OF EXPERTISE IN MARINE FIREFIGHTING AMONG THE LEADERS AND THE EFFECTIVE LEVEL OF TRAINING IN MARINE FIREFIGHTING AMONG THE FIREFIGHTERS, FOR A GIVEN PORT AREA

FIRE FIGHTERS	SHIP TYPE	$\underline{E}\,\underline{T}$	$\underline{E}T$	$E\underline{T}$	ET	ST
LAND-BASED FORCES	*ALL*	0.65	0.12	0.08	0.09	0.06
SHIP-BASED FORCES	*FREIGHTER*	0.08	0.77	0.01	0.14	--
	CONTAINER	0.08	0.77	0.01	0.14	--
	TANKER	0.00	0.40	0.00	0.60	--
	PASSENGER	0.03	0.57	0.02	0.38	--
	TANK BARGE	0.01	0.89	0.00	0.10	--

FIGURE IX-3 STATUS QUO, 1975: PROBABILITY OF FINDING SPECIAL SEATTLE PLAN TYPE OF EXPERTISE (S), EXPERTISE (E), OR NO EXPERTISE ($\underline{E}$) IN MARINE FIREFIGHTING AMONG THE LEADERSHIP OF THE FIREFIGHTING TEAM AND TRAINING (T) OR NO TRAINING ($\underline{T}$) IN MARINE FIREFIGHTING AMONG THE FIREFIGHTERS

lines, fire departments, and firefighting schools what percentage of ship officers could correctly deploy a built-in CO_2 system. The responses varied widely, from 20% to 90%. Naturally, the fire department personnel gave the ship officers a lower rating than did the shipping lines, but big differences of opinion existed even among the same types of experts. To resolve the disagreement, we built a simple model of the four sequential events that must take place for the built-in system to extinguish the fire. Figure IX-4 shows that first, the built-in system must be in place in the compartment; second, the system must be properly charged with agent and must be operational; third, the command decision to use the system must be made; and fourth, the system must be used correctly. The fourth step includes, for CO_2 and halon volume flooding systems, the securing of ventilation, the correct deployment of the system, and the allowance of sufficient time for cooling off before the space is reopened. These probabilities vary according to ship type, ship location, and fire location.

Figure IX-4 shows the case of a Level 2 cargo hold fire aboard a general cargo freighter at dock in a port city where the fire department is most accurately described as having low level training, but no specialized expertise in marine firefighting. The probability that a built-in system is in place in the engine room or cargo space of a given ship type is presented in Table IV-1 in the Fire Scenario Model; for this particular scenario, the probability is 65%. To determine the probability that the built-in system is properly charged with agent and is mechanically operational, we used reports of ship fires and interviewed fire protection engineers, naval architects, and safety personnel of shipping lines. As shown in Figure IX-4, the probability that it is operational for this case is 95%. We then used reports from ship fires and the judgment of marine fire school instructors, fire department marine division officers, ship deck and engineering officers, and representatives of shipping lines to assess the probability that the fire officers would choose to use the built-in system in specific fire scenarios, and the probability that they would use it correctly. In the cargo hold fire in Figure IX-4, for the training but no expertise case, these probabilities are 75% and 80%, respectively. The command decision assessment takes into account the fact that the low level training has made the fire officer aware of the advantages of the built-in system, but to deploy it, he must rely on ship personnel. The command decision, therefore, takes into account the fire officer's rapport with and confidence in the ship officers present, as well as the possibility of language barriers.

The probability that the system is correctly deployed represents our experts' consensus opinion that the ventilation is adequately secured, that the ship officer correctly activates the system, and that that fire department does not open the space prematurely. By multiplying the probabilities of each of the four links in the chain, we can compute from Figure IX-4 the probability that the built-in system is used correctly in this case as 0.65 x 0.95 x 0.75 x 0.80 = 0.37.

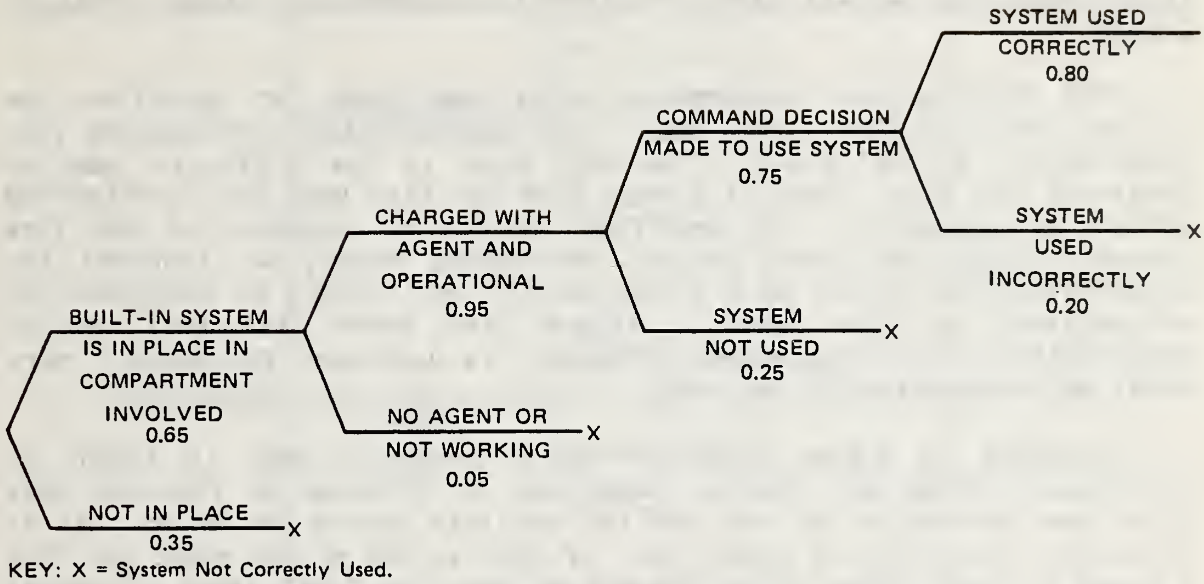


FIGURE IX-4 ASSESSMENT OF THE PROBABILITY THAT THE BUILT-IN SYSTEM WILL EXTINGUISH THE FIRE IN THE CASE OF CARGO-HOLD FIRE ON A FREIGHTER AT DOCK, WHERE THE FIRE IS FOUGHT BY A FIRE DEPARTMENT HAVING LOW-LEVEL TRAINING, BUT NO EXPERTISE IN MARINE FIREFIGHTING

In all cases, breaking down the built-in assessment into these four sequential events and discussing each one individually resolved much, but not all, of the disagreement. Differences of opinion remained about the fourth link, the correct use of the system in both the engine room and cargo holds. We decided to use the opinions of those experts with the broadest range of experience and the least bias. Figure IX-5 shows the probability that the built-in system is used correctly in each scenario. The zero probability shown in superstructure fires occurs because there are no built-in CO_2 or halon volume flooding systems in the living quarters.

Transition from Initial Level of Fire Involvement to Final Level of Damage

The Firefighting Performance Model has thus far specified the initial level of fire involvement that confronts the firefighters when they arrive on the scene. The next step is the difficult task of assessing the final level of damage from the fire when the firefighting effort is completed. For specified choices of elements of the Fire Scenario Model and Firefighting Performance Model, we assessed the probability that a fire of a given initial level could be contained and extinguished at that level. Figure IX-5 shows this full set of probabilities. The assessment procedure is discussed following a more detailed explanation of the model.

Consider an engine room fire on a freighter that is fought by land-based forces who have no expertise or training in fighting ship fires and who either do not use the built-in system or do not use it correctly. Figure IX-5 shows that, if they arrive on the scene and find a Level 1 fire, there is an 85% chance that the final level of damage will be Level 1. For the 15% of these fires that grow from Level 1 to Level 2 and for those fires that are initially confronted at Level 2, there is a 55% chance that the final level of damage will be Level 2. For the 45% of these fires that grow to Level 3 and those that are initially confronted at Level 3, there is a 41% chance that the final damage level is Level 3, etc. When the fire reaches Level 5, Figure IX-5 shows a 100% chance that the final level is Level 5 because this is the total loss of the ship. There is, however, a very small chance that a Level 5 fire can trigger a major port catastrophe such as the Texas City catastrophe; we denote this type of catastrophe by Level 6, and show separately in Figure IX-6 the probabilities that were assessed for Level 5 fires growing to Level 6.

Before discussing the process by which these probabilities were assessed, several comments should be made concerning general features of Figure IX-5. First, the built-in systems are very effective when properly used. They tend not to be used, however, on Level 1 and 2 fires in the engine room when at sea because such use would cause a shutdown of the propulsion plant. They tend not to be used on Level 4 fires in the cargo spaces because their use would have been attempted at

FIRE FIGHTERS	FIRE LOCATION	EXPERTISE, TRAINING	BUILT-IN USED CORRECTLY	FIRE LEVELS 1	2	3	4	5
LAND-BASED FORCES	ENGINE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	ST	YES (0.88)	0.99	0.99	0.99	0.99	1.00
			NO (0.12)	0.95	0.86	0.55	0.90	1.00
		ET	YES (0.88)	0.99	0.99	0.99	0.99	1.00
			NO (0.12)	0.95	0.86	0.50	0.90	1.00
		ET	YES (0.86)	0.99	0.99	0.99	0.99	1.00
			NO (0.14)	0.87	0.79	0.44	0.90	1.00
		ET	YES (0.45)	0.90	0.67	0.99	0.75	1.00
			NO (0.55)	0.90	0.67	0.44	0.75	1.00
		ET	YES (0.35)	0.85	0.55	0.99	0.70	1.00
			NO (0.65)	0.85	0.55	0.41	0.70	1.00
	SUPERSTRUCTURE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	ST	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.97	0.93	0.88	0.94	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.97	0.93	0.88	0.93	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.95	0.83	0.80	0.85	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.95	0.80	0.75	0.75	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.90	0.68	0.60	0.69	1.00
	CARGO (FREIGHTER, CONTAINER, PASSENGER)	ST	YES (0.61)	0.90	0.99	0.99	0.99	1.00
			NO (0.39)	0.90	0.84	0.80	0.99	1.00
		ET	YES (0.59)	0.90	0.99	0.99	0.98	1.00
			NO (0.41)	0.90	0.78	0.78	0.98	1.00
		ET	YES (0.56)	0.90	0.99	0.99	0.92	1.00
			NO (0.44)	0.90	0.68	0.70	0.92	1.00
		ET	YES (0.37)	0.90	0.99	0.99	0.77	1.00
			NO (0.63)	0.90	0.57	0.66	0.77	1.00
		ET	YES (0.32)	0.82	0.99	0.99	0.70	1.00
			NO (0.68)	0.82	0.47	0.65	0.70	1.00
	CARGO (TANKER)	ST	YES (0.24)	0.95	0.97	0.95	0.90	1.00
			NO (0.76)	0.90	0.92	0.85	0.80	1.00
		ET	YES (0.24)	0.95	0.97	0.95	0.90	1.00
			NO (0.76)	0.90	0.92	0.85	0.80	1.00
		ET	YES (0.24)	0.88	0.87	0.88	0.90	1.00
			NO (0.76)	0.83	0.82	0.80	0.80	1.00
		ET	YES (0.24)	0.90	0.90	0.70	0.65	1.00
			NO (0.76)	0.87	0.87	0.65	0.60	1.00
		ET	YES (0.24)	0.85	0.85	0.70	0.65	1.00
			NO (0.76)	0.80	0.80	0.65	0.60	1.00
	CARGO (TANK BARGE)	ST	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.90	0.90	0.85	0.83	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.90	0.90	0.85	0.83	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.83	0.80	0.75	0.60	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.87	0.85	0.75	0.55	1.00
		ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.80	0.75	0.70	0.50	1.00

FIGURE IX-5 PROBABILITIES (IN PARENTHESES) THAT THE BUILT-IN SYSTEM IS USED CORRECTLY AND THAT FIRES OF A GIVEN INITIAL LEVEL ARE EXTINGUISHED AT THAT LEVEL

FIRE FIGHTERS	FIRE LOCATION	EXPERTISE, TRAINING	BUILT-IN USED CORRECTLY	FIRE LEVELS 1	2	3	4	5
SHIP-BASED FORCES	ENGINE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	ET	YES (0.87)	0.95	0.86	0.99	0.50	1.00
			NO (0.13)	0.95	0.86	0.41	0.50	1.00
		E$\underline{T}$	YES (0.87)	0.91	0.64	0.99	0.50	1.00
			NO (0.13)	0.91	0.64	0.41	0.50	1.00
		$\underline{E}$T	YES (0.63)	0.93	0.84	0.99	0.50	1.00
			NO (0.37)	0.93	0.84	0.41	0.50	1.00
		$\underline{E}\underline{T}$	YES (0.53)	0.90	0.60	0.99	0.50	1.00
			NO (0.47)	0.90	0.60	0.41	0.50	1.00
	SUPERSTRUCTURE (FREIGHTER, CONTAINER, TANKER, PASSENGER)	ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.95	0.75	0.50	0.53	1.00
		E$\underline{T}$	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.73	0.65	0.45	0.45	1.00
		$\underline{E}$T	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.85	0.60	0.45	0.45	1.00
		$\underline{E}\underline{T}$	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.66	0.50	0.30	0.40	1.00
	CARGO (FREIGHTER, CONTAINER, PASSENGER)	ET	YES (0.88)	0.99	0.99	0.99	0.75	1.00
			NO (0.12)	0.90	0.70	0.65	0.75	1.00
		E$\underline{T}$	YES (0.88)	0.99	0.99	0.99	0.65	1.00
			NO (0.12)	0.80	0.55	0.55	0.65	1.00
		$\underline{E}$T	YES (0.43)	0.99	0.99	0.99	0.65	1.00
			NO (0.57)	0.85	0.62	0.50	0.65	1.00
		$\underline{E}\underline{T}$	YES (0.43)	0.99	0.99	0.99	0.60	1.00
			NO (0.57)	0.70	0.47	0.45	0.60	1.00
	CARGO (TANKER)	ET	YES (0.50)	0.90	0.95	0.92	0.73	1.00
			NO (0.50)	0.90	0.90	0.80	0.68	1.00
		E$\underline{T}$	YES (0.50)	0.83	0.85	0.85	0.70	1.00
			NO (0.50)	0.83	0.80	0.70	0.65	1.00
		$\underline{E}$T	YES (0.50)	0.87	0.90	0.85	0.70	1.00
			NO (0.50)	0.87	0.85	0.65	0.60	1.00
		$\underline{E}\underline{T}$	YES (0.50)	0.80	0.83	0.80	0.65	1.00
			NO (0.50)	0.80	0.75	0.60	0.55	1.00
	CARGO (TANK BARGE)	ET	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.80	0.60	0.60	0.20	1.00
		E$\underline{T}$	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.80	0.60	0.60	0.20	1.00
		$\underline{E}$T	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.80	0.40	0.50	0.20	1.00
		$\underline{E}\underline{T}$	YES (0.00)	--	--	--	--	--
			NO (1.00)	0.60	0.40	0.50	0.20	1.00

KEY: S = SPECIAL SEATTLE PLAN TYPE OF EXPERTISE IN MARINE FIREFIGHTING LEADERSHIP
E = EXPERTISE
$\underline{E}$ = NO EXPERTISE
T = TRAINING IN MARINE FIREFIGHTING FOR FIREFIGHTERS
$\underline{T}$ = NO TRAINING

FIGURE IX-5 PROBABILITIES (IN PARENTHESES) THAT THE BUILT-IN SYSTEM IS USED CORRECTLY AND THAT FIRES OF A GIVEN INITIAL LEVEL ARE EXTINGUISHED AT THAT LEVEL (CONTINUED)

Level 3 or earlier, and the system is now exhausted or inoperative. In both these cases, the numbers appropriate for manual firefighting have been used. Second, the details of each fire level in each fire scenario must be considered: that is, whether there is enough fuel to allow the fire to progress to the next level, whether there is sufficient ventilation to support a raging fire, whether there are physical barriers that contain the fire, whether there is time to bring the ship into a port for firefighting, whether the ship's propulsion and pumping capacity are impaired, whether firefighters can gain access to the seat of the fire, whether there is sufficient agent available for fighting the fire, etc. Third, we made the assumptions that the Level 6 port catastrophe can occur only if a Level 5 fire occurs and that the factors that lead to a port catastrophe (such as strong onshore winds and tides) are beyond the control of the firefighters.

As should be evident, the assessment of these firefighting performance probabilities is anything but easy. For one thing, major ship fires are rare enough that few people have had firsthand experience in fighting more than one large and complicated ship fire, and it is these people who can best furnish estimates. Because they were involved in the actual fighting of the fires, they are in a better position than anyone else to estimate how various levels of marine firefighting expertise and training would have aided the firefighting effort.

It should be noted that the various levels of expertise and training have been defined in such a way that they do not correspond to hypothetical, untried options; all of these levels can be found in various U.S. ports where major ship fires have occurred. Thus, the assessments reflect actual experience as far as possible.

The first round of assessments was conducted during visits to many of the major port areas of the United States. During these visits, members of the municipal and port authority fire departments and representatives of shipping lines were asked about ship fires that they or their departments had fought. Each described the fire scenario and was then asked: What was the initial level of fire involvement? What were the levels of expertise and training of the officers and firefighters? What equipment, agent, and tactics were used? What was the final level of damage from the fire? Assessments were then made as to how other levels of expertise, training, and equipment would have affected the outcome of that particular fire.

The general form of the assessment procedure (used formally or informally) was:

Fire Scenario (preferably an actual fire that the individual fought or with which he was familiar):

A general cargo freighter, 12,000 gross tons, is at dock. A slowly developing fire is discovered in the 'tween deck of a closed cargo hold; the 'tween deck is 75% filled with cargo,

and no built-in fire suppression system is in place. When the fire department arrives, 25% of the cargo in the deck is involved.

Assessment Procedure

Consider 10 such fires. In how many cases will the fire be contained at this level, and in how many cases will it destroy all cargo in the deck:

(1) If fire department has no special marine fire training?

4.7 Contained   5.3 Destroy all cargo in deck

(2) If fire department recently had 40 hours in-service training (ship familiarization)?

5.7 Contained   4.3 Destroy all cargo in deck

The figures entered above are the final consensus responses of the experts for this Level 2 cargo hold fire. Numerous such assessments were made for all transition probabilities between fire levels for all fire scenarios, both for the case where the built-in system is used correctly and for the case where it is not used correctly. The principal sources for these assessments were:

Cdr. Benson	New Orleans Port Commission
Capt. T. Bingham	New York City Fire Department
Mr. F. Boland	NMU Training Director
Chief V. Buss	Portland, Oregon Fire Department
Mr. J. Carnes	Maritime Administration
Dep. Chief H. Catterton	Baltimore Fire Department
Capt. O. Darnell	Lykes Bros. Lines
Capt. R. Hansen	Seattle Fire Department
Instructor P. Harrison	Calhoun MEBA School
Asst. Chief D. Jeffrey	Massport Fire Department
Instructor D. Krabbenschmidt	MSC Firefighting School
Capt. J. Maag	Everett, Washington Fire Dept.
Dep. Fire Marshall J. Maskill	Philadelphia Fire Department
Superintendent W. McCrossen	New Orleans Fire Department
Chief M. Mitchell	Los Angeles Fire Department
Battalion Chief G. O'Neill	New York City Fire Department

Capt. C. Otterberg	Maritime Administration
Commissioner R. Quinn	Chicago Fire Department
Asst. Chief R. Rose	San Francisco Fire Department
Dep. Chief T. Rush	New York City Fire Department
Capt. D. Savastio	Moore McCormack Lines
Capt. C. Wehrung	Lykes Bros. Lines

Several other members of fire departments, port authorities, and shipping lines also assisted us in these assessments. Numerous technical judgments were provided by Mr. Raymond Alger and Mr. Stanley Martin of SRI International's Fire Research Group.

Preliminary runs of the complete model (see section entitled Calibration of the Model) showed that the experts underestimated the ability of fire departments and ship crews to prevent fires from growing to the next higher level. Several sources for this bias were identified. First, it is difficult to keep in mind that the levels of fire involvement cover a wide range of fire sizes. Second, it is difficult to remember that many fires are fuel-limited and ventilation-controlled. Third, fire departments often do not see the fires extinguished by the crew; they respond to those that grow larger. Fourth, it is easy to remember mistakes that were made in fighting a fire; it is not valid to assume the same mistakes would inevitably have been made under other circumstances, especially as ship officers, shipping line and insurance representatives, Coast Guard personnel, and the like often have time to offer advice and warnings in the case of large fires.

Because the assessment of these transition probabilities is such a critical part of the analysis, we decided to bring together a small number of marine firefighting experts for a 3-day intensive discussion to resolve the disagreements and refine the previous assessments. This forum took place on May 3-5, 1978 at SRI headquarters in Menlo Park, California. The number of experts was limited to five to keep the discussion manageable. The individuals invited to participate in this forum were carefully chosen from among those we had previously interviewed to represent depth in experience and diversity of background and opinion. The five marine firefighting experts who participated in the forum were:

Captain Robert L. Hansen of the Seattle Fire Department, the key figure in the development of the Seattle marine fire protection program.

Assistant Chief W. Donald Jeffrey of the Massachusetts Port Authority Fire Department, a former mariner with firefighting leadership experience both at sea and on land.

Instructor Dale Krabbenschmidt of the Military Sealift Command Firefighting School at Treasure Island, California, a licensed master who is involved daily in the firefighting training of U.S. merchant marine crews.

Assistant Chief Robert Rose of the San Francisco Fire Department, who has previous service in the Coast Guard and who now directs planning and research for all department functions including pier and ship fires.

Deputy Chief Thomas J. Rush, Marine Division, New York City Fire Department, whose knowledge and experience in marine firefighting is respected nationwide.

Through discussion of the many different considerations that go into the assessment of each of the probabilities and the mutual exchange of opinion, the participants reached a surprisingly good accord on most of the assessments. Much of the disagreement they had prior to our analysis came from general statements of opinion about cost-effectiveness in which the reduction in loss from a fire protection program was not considered separately from the increase in cost. By systematically proceeding through the various combinations of elements in the Fire Scenario and Firefighting Performance Models, the experts were evaluating the impact of the various programs on the identical fire challenge and responded in remarkable agreement. Remaining differences of opinion were small and were easily reconciled in the final adjustments performed in the calibration of the model described later in Chapter IX.

The final assessments that must be made concern the Level 6 port catastrophe. The prototype for this type of fire is the Texas City, Texas catastrophe of April 16, 1947 in which the French freighter Grandcamp and the American freighter Highflyer, both loaded with ammonium nitrate, exploded, killing or incapacitating most of the firefighting forces and starting many fires in waterfront chemical plants. The end result of this catastrophic event was 510 deaths and a tremendous amount of property and commercial damage.

It is difficult to persuade firefighting experts even to speculate on the probability of such a rare and catastrophic event occurring. However, for the purposes of this study, it is important to quantify the best information available so that the Level 6 fire can be put in perspective against the rest of the marine fire problem. We have, therefore, gathered the best estimates that were available to us to construct the model.

We first observed that a fire of such magnitude certainly destroys the ship on which it starts, so it can occur only if a Level 5 occurs. The possibility of such a major conflagration starting from a spark from a minor ship fire should not be included as part of the ship fire problem because it could just as well have been started by any other source. Because military ship fires are not within the scope of this study and ordnance is no longer either loaded or unloaded in any sizeable quantity in commercial ports, munition ship accidents are excluded.

For freighters and bulk carriers, the most likely scenario to cause a Level 6 fire is a fire that breaks out in a cargo hold that has a large quantity of high explosives, when the ship is at dock in the vicinity of valuable waterfront property. Because large quantities of such materials are not allowed to be loaded or unloaded in merchant marine ports, the explosive detonating and causing the Level 6 fire is likely to be a substance whose highly explosive properties are not commonly known. As an example, the explosive properties of the ammonium nitrate fertilizer that caused the Texas City incident were not commonly known prior to that disaster. On the basis of discussions with various port authority and Coast Guard personnel, we estimated that in Level 5 freighter and bulk carrier fires originating in cargo holds (themselves being rare events), such an explosive is present one-fifteenth of the time and may well be the reason the fire reaches Level 5. Further, we estimated that in such fires at dock, there is a one-third chance that property on the order of $1 billion in value (sufficiently valuable for Level 6) is nearby. Thus, the probability that a Level 5 fire that originated in the cargo hold of a freighter (or bulk carrier) at dock can lead to a Level 6 fire is 1/15 x 1/3 = 1/45, the number shown in Figure IX-6.

For Level 5 fires starting in the engine room or superstructure of a freighter at dock, the probability of a Level 6 fire is only one-fourth as large (see Figure IX-6). Several reasons account for this decrease. First, a cargo fire reaches Level 5 usually when there is some dangerous cargo on board; the same correlation does not hold for engine room or superstructure fires. Second, it is easier to protect dangerous sections of the cargo space if the fire originates in the engine room or superstructure. Third, in the case of engine room or superstructure fires, it may be easier to take drastic measures such as towing the vessel to sea or scuttling it to avoid a potential catastrophe.

For containerships, the same kind of estimates were made, but here the probabilities are only three-fourths of the freighter estimates because such a cargo is less likely to be carried in containers and is less vulnerable. For passenger ships, the likelihood of carrying such dangerous cargoes is negligibly small.

For tankers, explosions occur only in empty tanks and consequently do not have enough energy of themselves to cause a Level 6 fire. Strong onshore winds combined with strong currents or tides and a large

SHIP TYPE	SHIP LOCATION	FIRE LOCATION	PROBABILITY LEVEL 5→LEVEL 6
FREIGHTER	AT DOCK	ENGINE	0.006
		CARGO	0.022
		SUPERSTRUCTURE	0.006
CONTAINER	AT DOCK	ENGINE	0.004
		CARGO	0.017
		SUPERSTRUCTURE	0.004
TANKER	AT DOCK	ENGINE	0.013
		CARGO	0.040
		SUPERSTRUCTURE	0.013
	IN HARBOR, NEAR LAND	ENGINE	0.001
		CARGO	0.003
		SUPERSTRUCTURE	0.001

*Probabilities not listed are negligible.

FIGURE IX-6 PROBABILITY THAT A LEVEL 5 FIRE WILL DEVELOP INTO A LEVEL 6 FIRE *

quantity of burning oil could, however, lead to a major waterfront fire that could cause Level 6 destruction. Again, a Level 5 fire is needed to generate the Level 6 fire. Of Level 5 tanker fires, we estimated that four out of five involve enough oil to start such a fire, and in one case out of ten, the wind and tides will be severe enough to start major fires ashore. We further estimated a fifty-fifty chance that shore facilities valuable enough for Level 6 damage are nearby. For Level 5 fires that start in the superstructure or the engine room, we estimated that only one in three will extend to the cargo in such a way as to create the conditions necessary for a Level 6 fire. The resultant probabilities are entered in Figure IX-6. In harbor, a tanker could conceivably create an oil fire on the water that could be carried ashore and lead to Level 6; these probabilities are also entered in Figure IX-6.

Another possibility for a Level 6 catastrophe is the release of noxious fumes from a ship fire that subsequently kill a great number of people. Thousands of people would have to be killed to reach Level 6 magnitude (see Chapter VIII); since this event would require a highly unlikely combination of weather conditions, population density, and failure to evacuate the people exposed, we assign it a much lower probability than the scenarios above. Other extreme scenarios such as a burning tanker aground under a bridge are not likely to generate enough damage to qualify as Level 6.

By logically combining these probabilities, the model enables us to calculate the expected frequency of the most serious fires. On the average, total loss of a ship from fire (Level 5) is expected to occur once every 10 months. A ship fire leading to a port catastrophe (Level 6) is expected to occur once every 80 years, again a long-term average.

Finally, there is one incident that does not fit directly into the model we have developed: a liquified natural gas tanker has a massive spill and the vapor cloud ignites over a heavily populated or heavily industrialized area. This possibility is discussed separately at the end of this chapter.

Calibration of the Model

Much information is available concerning the spectrum of final levels of damage in ship fires. The primary sources we used were Coast Guard records and American Hull Insurance Syndicate records. The Coast Guard records explicitly indicate total losses (Level 5) and constructive total losses (part of Level 4). These records also list the estimated monetary damages to the vessel. Taking into account the age and size of the vessel (see Chapter VIII) and adjusting for inflation over the 15-year period of the records, we have reconstructed the spectrum of final levels of damage from Coast Guard records. The Hull Syndicate 6-year record provided a second source of statistics on

final levels of damage and a method for cross checking individual incidents.

It should be noted that although identification of a number of fires in both sets of records revealed that the Coast Guard estimates of vessel damage were too low by a factor of 2.03, the patterns were consistent and the records could be used to give the final damage level spectrum presented in Figure IX-7. Figure IX-7 shows, for all fires of a given ship type and fire location, the percentage that were in each final level of damage. This status quo distribution of damage levels is a critical part of this analysis. Via the Value Model, it provides the basis for the estimate of current marine fire losses.

This estimate was developed in the following way: from Figure VI-1, we determined that there are an average of 22.4 freighter fires per year and that of these fires, 10.2 are engine room fires. Further, 6.2 of these 10.2 fires occur at dock, 0.6 in harbor, and the remaining 3.4 occur near land or at sea. From Figure IX-7, we then determined that 59% of all freighter engine room fires, or 6.02 fires per year, cause Level 1 damage. Similarly, 2.35 freighter engine room fires per year cause Level 2 damage, 1.22 cause Level 3 damage, 0.41 cause Level 4 damage, and 0.20 cause Level 5 damage. Figure IX-6 then allowed us to compute that the expected number of freighter engine room fires progressing to Level 6 is 0.00074 per year (for freighter engine room fires, only fires at dock have this potential).

We then used the Value Model to convert damage levels to equivalent dollar loss. Adding the dollar losses for vessel, cargo, waterfront, commercial, and human damages (converting deaths and injuries to their dollar equivalents), we computed that each Level 1 freighter engine room fire has an expected loss of $38,730. This amount, multiplied by the 6.02 such fires per year, yielded $233,154 for all Level 1 freighter engine room fires per year. The same procedure was carried out for the Level 2, 3, and 4 freighter engine room fires. For Levels 5 and 6, care must be taken in using the Value Model because waterfront and commercial losses depend on ship location. It was for this reason that we had to distinguish in the previous paragraph the percentage of Level 5 fires at dock from the percentage in harbor and the percentage near land and at sea.

After the expected equivalent dollar loss per year for freighter engine room fires was computed, the process was repeated for each fire location for each ship type. The sum total of all categories of damage for all types of vessels became the estimate of the marine fire losses.

The entire model was run and adjustments were made so that the model would reproduce the historical results shown in Figure IX-7. Such an adjustment process is necessary so that the individual assessments made in each component of the systems model combine to reproduce the historical results. Two different kinds of adjustment were made. First, minor adjustments were made to the initial fire level

SHIP TYPE	FIRE LOCATION	FINAL DAMAGE LEVEL* 1	2	3	4	5
FREIGHTER	ENGINE	0.59	0.23	0.12	0.04	0.02
	CARGO	0.47	0.35	0.10	0.06	0.03
	SUPSTR	0.49	0.31	0.08	0.07	0.05
CONTAINER	ENGINE	0.59	0.23	0.12	0.04	0.02
	CARGO	0.70	0.17	0.07	0.05	0.02
	SUPSTR	0.47	0.30	0.09	0.08	0.06
TANKER	ENGINE	0.56	0.25	0.13	0.04	0.02
	CARGO	0.23	0.26	0.20	0.16	0.16
	SUPSTR	0.53	0.33	0.08	0.04	0.03
PASSENGER	ENGINE	0.59	0.24	0.12	0.04	0.02
	CARGO	0.46	0.38	0.10	0.04	0.02
	SUPSTR	0.52	0.32	0.08	0.05	0.03
TANK BARGE	CARGO	0.23	0.25	0.21	0.10	0.21
CARGO BARGE	CARGO	0.35	0.30	0.20	0.10	0.05
FISHING BOAT	ALL	0.20	0.20	0.20	0.20	0.20
TUG,TOW	ENGINE	0.40	0.34	0.18	0.03	0.05
	SUPSTR	0.25	0.25	0.25	0.13	0.12
MISC	ALL	0.16	0.18	0.16	0.29	0.21

* Each row adds to 100%.

FIGURE IX-7 STATUS QUO, 1975: THE FRACTION OF SHIP FIRES RESULTING IN EACH FINAL DAMAGE LEVEL, FOR EACH SHIP TYPE AND FIRE LOCATION

distribution or the firefighting performance assessments for specific fire scenarios. These adjustments were well within the region of uncertainty of the original assessments. Running the model with these minor corrections enabled us to reproduce the historical distribution of final damage levels for almost all fire scenarios. In a few cases, however, there was evidence of a strong negative bias in the experts' judgments of the performance of fire departments with no marine fire training and ship crews with no firefighting training.

One reason for such a bias is the tendency for the experts to assume that ship fires always have sufficient fuel and oxygen to grow to the next higher level. Observing this cognitive bias during the discussions in our forum, we enriched the descriptions of fire scenarios by conditioning the assessments on the availability of sufficient fuel and oxygen to enable the fire, even if not fought, to grow to the next higher level. But even with this correction, the model--using the experts' assessments--produced a set of final damage levels in a few cases that were far worse than the known historical pattern. To reconstruct the historical losses in these few cases, we simultaneously worked forward from the initial fire level distribution and backwards from the historical final level distribution to establish consistent transition probabilities. Having calibrated the model to reproduce the final damage spectrum of Figure IX-7, we produced a tool that yields a good and reliable representation of the absolute size of the status quo marine fire problem and an even better means of measuring the expected reduction in loss from the various alternative marine fire protection programs.

It should be noted that this complicated calibration process was performed only for merchant marine vessels and tank barges. For the tugs, tows, fishing boats, and other smaller vessels, where the impact of the alternatives is much smaller and can be assessed directly, no firefighting performance model was built, and therefore no calibration process was needed.

Calibration of our estimates for Level 6 is more difficult because this type of catastrophe is extremely rare. Our model predicts that a Level 6 fire can be expected once every 80 years, and this fire is 18 times more likely to occur because of a tanker fire than a freighter fire.

The only Level 6 fire that has occurred in the past 80 years is the Texas City incident of 1947. (It should be remembered that military ships are excluded from our study.) It is highly unlikely that the Texas City incident would be repeated because firefighters and ship operators are now aware of the dangers of cargoes such as ammonium nitrate. On the other hand, of course, there are new products being transported that may present as yet unknown dangers.

Finally, the reasonableness of the estimate that an average of one tanker fire per century will develop into a Level 6 catastrophe is

difficult to infer from the historical data. To our and our experts' best knowledge, there have been no such fires in the past, but there are indications that some situations have had the potential. To quote one such instance, Conclusion #13 of the Marine Board of Investigation Report on the collision between SS Edgar M. Queeny and S/T Corinthos at Marcus Hook, Pennsylvania on January 31, 1975 states:

> Common ordinary luck was a principal influence responsible for averting a catastrophic conflagration and/or release of toxic fumes of uncontrollable magnitude in the Marcus Hook area. A lack of wind isolated the fire from the British Petroleum Refinery and the array of similar surrounding refineries and also permitted the Edgar M. Queeny to remain alongside the Corinthos inferno for at least 8 minutes and escape relatively unscathed.

The probability assessments discussed above were used for the base case run of the model. Sensitivity of our results to the critical assumptions is shown where the results are presented in Chapter IV.

Status Quo, 1980-2000

Just as new trends and programs are changing elements in the Fire Scenario and Value Models independently of the alternatives we are evaluating, new trends and programs are changing elements of the Firefighting Performance Model as well. Analogous adjustments to the Firefighting Performance Model must be made so that the base case, representing the status quo alternative, reflects the expected situation during the 1980-2000 period. It should be emphasized that these changes do not reflect any of the alternatives we are considering; they are programs already in operation or soon to be put into operation, and any alternatives represented in this study will have an effect over and above this changed background.

The principal change in the Firefighting Performance Model is in the area of firefighting training for ship crews. New training programs will be implemented as a result of recent IMCO agreements and Coast Guard regulations. First, a Coast Guard requirement for a tankerman certificate for various ratings on all U.S. flag tankships and tank barges is imminent. Second, via agreements reached in a recent IMCO conference, the tankerman rating will apply to personnel on all tankers engaged in international trade. Thus, the tankerman rating will apply to all tankships and tank barges included in the scope of this study.

The tankerman rating must be renewed every 5 years; by the early 1980's, the relevant crew population will have been certified and the program should be in full force. In terms of our model, this tankerman rating changes the probabilities of the level of training of the crew expected to fight fires on tankships and tank barges. We estimate that

this tankerman rating program will virtually eliminate the chance (a 99% reduction in probability) that in the future a fire occurs on a tankship or tank barge with an untrained crew. The revised and updated assessments, which are used in the model for the 1980-2000 base case in place of those for the 1975 base case, are shown in Figure IX-8.

In addition to the tankerman rating, there is another IMCO agreement to be implemented in the near future. At a recent IMCO conference in London, which took place during the course of our study, mandatory firefighting training for the majority of merchant seamen on all ocean going vessels was discussed. This mandatory training would apply to all deck and engineering officers, all navigational and engine room watch standers, and all radio operators. Sources at the Maritime Administration have advised us that ratification of this proposal is virtually certain by 1982, and that when ratified, the Coast Guard will extend the regulation to include all domestic shipping as well. Consequently, all merchant vessels, regardless of cargo, and all tank barges will be required to have officers and crews trained in firefighting. The complete details of the fire training are not yet specified, but it is expected that officers and numerous crew ratings will have to renew their fire training every 5 years. For some lower ratings, the renewal periods will be less frequent.

Four new marine firefighting schools are being put into operation this year by the Maritime Administration to begin the huge training task mandated by these new agreements. Clearly not all the seamen will be trained at once, but training experts associated with the schools expect the first round of the program to be achieved over the course of a few years. Obviously, such a major investment in the training of tens of thousands of seamen will affect the 1980-2000 background case in the model. Even if the program has problems in implementation, and even if many less people are trained, there would still be at least a special squad of five seamen and one officer with recent firefighting training aboard every ship. We estimate that, allowing for turnover of crews and for the fact that this program has lower priority than that for tankermen, there will be a 90% reduction in the probability that, in the future, a fire will break out on a freighter, container, or passenger ship with an untrained crew. The updated and revised probabilities of the levels of expertise and training for ship-based firefighting forces are listed in Figure IX-8.

We would like to point out that low level firefighting training for ship crews was one of the alternatives that we analyzed in the early phases of our study. However, this training program will be implemented in the very near future. Consequently, it is becoming part of the background or status quo base case for the future, rather than a decision alternative to be considered in this study. The other alternatives must therefore be evaluated against a background case that takes account over time of the impact of these tankerman and dry cargo crew training programs.

FIRE FIGHTERS	*SHIP TYPE*	$\underline{E}\underline{T}$	$\underline{E}T$	$E\underline{T}$	*ET*	*ST*
LAND BASED FORCES	*ALL*	0.65	0.12	0.08	0.09	0.06
SHIP BASED FORCES	*FREIGHTER*	0.75	0.10	0.13	0.02	"
	CONTAINER	0.75	0.10	0.13	0.02	"
	TANKER	0.20	0.20	0.30	0.30	"
	PASSENGER	0.30	0.30	0.20	0.20	"
	TANK BARGE	0.80	0.10	0.10	0.00	"

FIGURE IX-8 STATUS QUO, 1980-2000: PROBABILITY OF FINDING SPECIAL SEATTLE PLAN TYPE OF EXPERTISE (S), EXPERTISE (E), OR NO EXPERTISE ($\underline{E}$) IN MARINE FIREFIGHTING AMONG THE LEADERSHIP OF THE FIREFIGHTING TEAM AND TRAINING (T) OR NO TRAINING ($\underline{T}$) IN MARINE FIREFIGHTING AMONG THE FIREFIGHTERS

Our model was originally constructed to allow us to compute the reduction in loss expected from these training programs. These computations are still performed and account for part of the difference between the size of the marine fire problem for the 1975 status quo and for the 1980-2000 status quo (see Chapter II). The rest of the difference arises from the new regulations and trends described in the Fire Scenario and Value Models.

The Catastrophic LNG Fire

One task in this study was a brief effort to examine the LNG catastrophic fire in the perspective of the entire marine fire problem. Level 5 or smaller LNG ship fires are accounted for in our model; the special circumstances that could lead to a Level 6 LNG fire, however, are not accounted for in the model; therefore, a special catastrophic LNG fire model was built. To construct this model, we reviewed available literature and conducted a series of interviews with LNG experts. The literature survey and interviews revealed the following conclusions: (1) Sabotage is the most likely initiating event for an LNG port catastrophe (2) One or more tanks would have to be ruptured to provide enough fuel for an LNG port catastrophe (3) If one or more tanks were ruptured, immediate ignition of the LNG vapor cloud is almost certain (4) Detonation of an unconfined LNG vapor cloud can be ruled out on physical grounds and (5) If a large spill occurs and there is no immediate ignition, the fire department could deliberately ignite the cloud to prevent it from drifting into a highly populated or high value district.

None of the articles or reports we reviewed nor any of the individuals we interviewed were able to answer two critical questions: What is the probability of this Level 6 LNG fire? What is the equivalent dollar loss if it occurs? They did, however, provide the elements of the model and some of the likelihood judgments needed to address these questions.

The first step in modeling this catastrophe was enumerating events that could initiate the rupture of one or more tanks of an LNG tanker. The set of initiating events included sabotage, collision, grounding, severe weather and lightning, earthquake and tidal wave, missile or aircraft penetration, and enemy bombardment; other events that could lead to the same consequences were estimated to have negligibly small probabilities. For each type of initiating event, an estimate was made of the number of times per year one or more tanks would be ruptured. Where relevant, these estimates began with comparable figures for tankships and were then adjusted for the smaller population and the additional safety precautions taken for LNG ships. A probability tree similar to that shown in Figure IX-9 was then constructed for each initiating event. Figure IX-9 shows only the tree for sabotage, the event generating the highest probability of catastrophe.

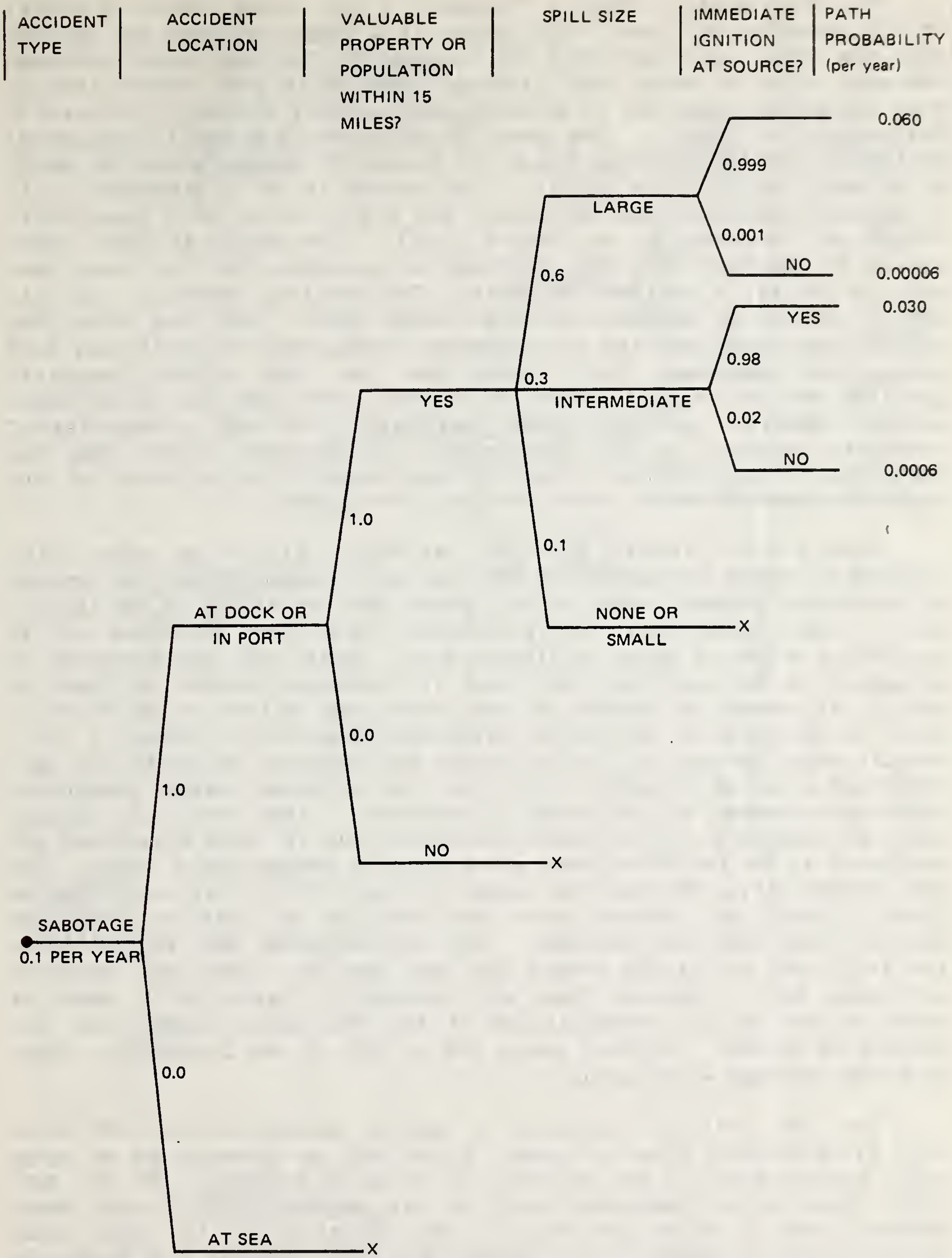
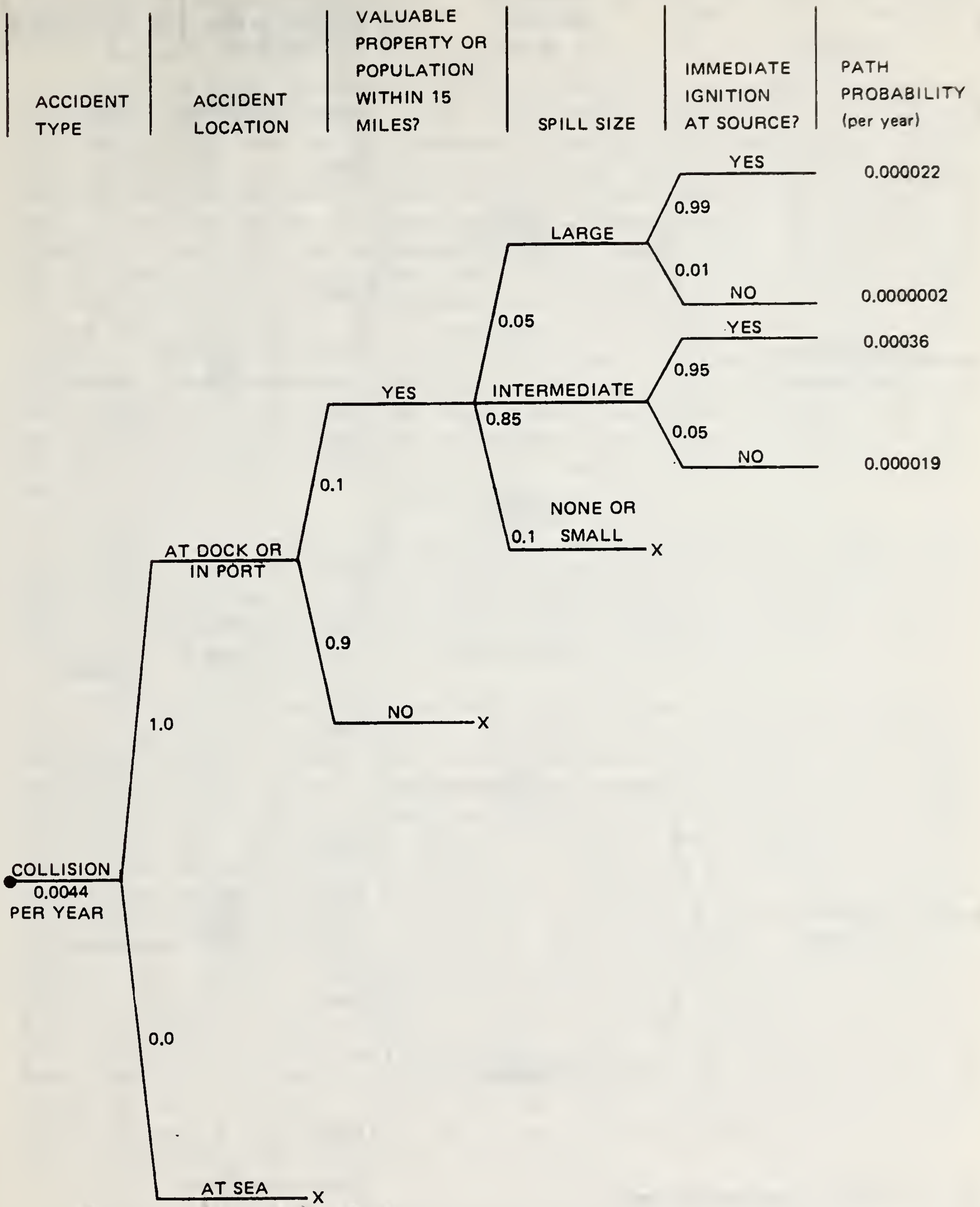


FIGURE IX-9 PROBABILITY TREE TO DETERMINE LIKELIHOOD THAT SABOTAGE YIELDS THE NECESSARY CONDITIONS FOR LNG PORT CATASTROPHE

The sabotage tree shows a frequency of one attempt every 10 years, or 0.1 attempts per year; this number is a rough estimate not derived from any data. The next sets of branches in the tree show that such sabotage attempts would take place at dock or in port rather than at sea, and within 15 miles of property sufficiently valuable for Level 6 destruction to occur. The node in the tree for spill size shows estimates that the saboteur has a 10% chance of causing either no spill or a small controllable spill, a 30% chance of an intermediate spill (1,000,000 gallons or one LNG tank), and a 60% chance of a large spill (10,000,000 gallons or an entire ship). We emphasize that these estimates represent the best information available and are used here only to provide a ballpark estimate. The critical question, then, is whether or not an immediate ignition takes place. SRI fire scientists believe that even with the most advanced techniques, there is only a 2% chance that saboteurs could break open one tank without immediate ignition and only a 0.1% chance they could break open all of the tanks without immediate ignition. The reason for this high probability of immediate ignition is the large number of ignition sources from the rupturing of the tank and from the ship itself, in the midst of the highly combustible vapor cloud that would be formed.

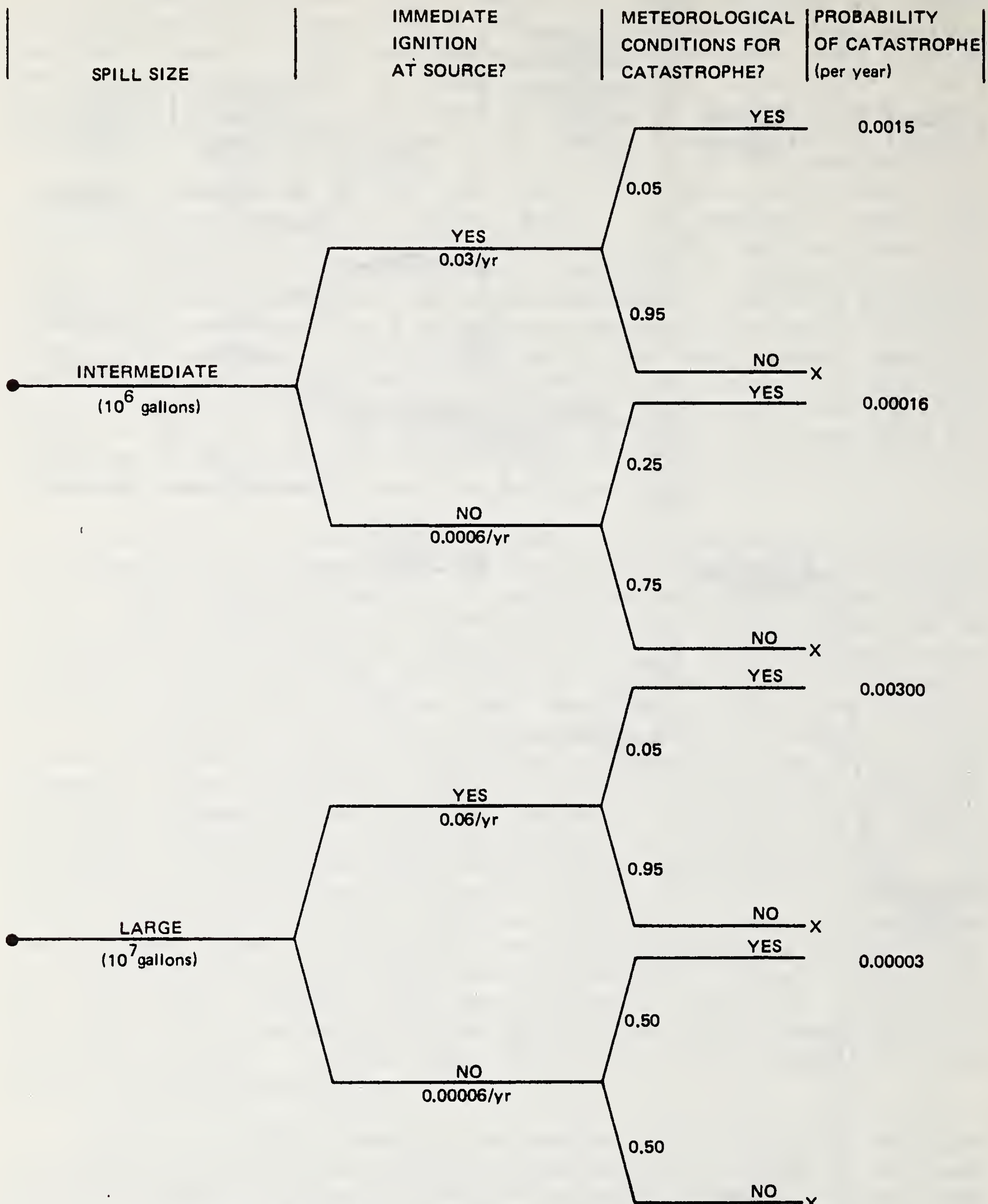
Figure IX-9 shows, for the sabotage initiating event, the individual branch probabilities and the path probabilities (the product of the branch probabilities) of all paths that could lead to the Level 6 fire. For comparison, the probability tree for collision as an initiating event is shown in Figure IX-10. Note that the frequency is estimated to be less than half that for sabotage: 0.0044 per year is just (0.44 tanker collisions per year resulting in fire or explosion) x (0.1, an estimate of the future ratio of LNG ships to tankers) x (0.5, because only one-half of the LNG ships are expected to be in the same congested areas as tankers) x (0.2 for the additional safety design and regulated movement of LNG ships in harbors). Also note that because most LNG terminals are in remote locations, 90% of these collisions are estimated to be far from areas where Level 6 damage could occur. The path probabilities for the four paths in Figure IX-10 that could lead to Level 6 fires are computed; note that they are an order of magnitude smaller than those for sabotage. The corresponding path probabilities for the other initiating events are even smaller; therefore, they are not shown here. Instead, they are included in Figure IX-11, where we show the sum of the probabilities of the four paths summed over all initiating events. In each case, 96% to 99% of the probability comes from the sabotage event alone.

The next critical question is whether meteorological conditions will allow Level 6 fires to occur, given that an intermediate or large spill has occurred in the vicinity of valuable property. In the case where there is an immediate ignition, we estimate that a wind speed greater than 30 miles per hour in the direction of the high value district would result in a Level 6 fire; whether the spill is intermediate or large, this strong wind would spread the fire beyond the control of the fire department. We made a rough estimate that winds at



KEY: X = LNG Port Catastrophe Not Possible.

FIGURE IX-10 PROBABILITY TREE TO DETERMINE LIKELIHOOD THAT COLLISION YIELDS THE NECESSARY CONDITIONS FOR LNG PORT CATASTROPHE



KEY: X = LNG Port Catastrophe Not Possible.

FIGURE IX-11 PROBABILITY TREE TO DETERMINE LIKELIHOOD OF LNG PORT CATASTROPHE

the Boston LNG terminal attain this speed and direction 1 day in 20, or 5% of the time. In the absence of such a wind, the fire department would be able to contain the LNG fire at the waterfront if immediate ignition occurred at the ship.

If there is no immediate ignition, the critical question is how far the unignited vapor could spread and remain combustible. A study by A.D. Little, included in the appendix of the LNG/LPG contingency plan of the Captain of the Port of Boston, gives estimates of the maximum distance of propagation of such a vapor cloud; this figure depends on spill size and atmospheric conditions. The maximum extent of the flammable cloud from an intermediate spill ranges from 1/2 mile during the daytime, with a 10-12 knot wind, to 6 miles on a calm, clear night. For the large spill, the maximum extent ranges from 1 and 1/2 miles during the day, with a 10-12 knot wind, to 15 miles on a calm, clear night. The report unfortunately does not provide the probability distributions on these atmospheric conditions. In their absence, we made rough estimates that the atmospheric conditions necessary for the Level 6 fire in the case of an intermediate spill occur 25% of the time, and 50% of the time in the case of the large spill (in the case of no immediate ignition).

Figure IX-11 shows the resulting path probabilities using these estimates. The sum of path probabilities leading to the Level 6 fire from all initiating events is 0.0046. This figure, multiplied by the nominal $1 billion loss for Level 6 fires, yields an expected loss per year of $4.64 million from the catastrophic LNG fire.

This expected loss does not take into account the fire department's ability to ignite deliberately a flammable vapor cloud approaching a metropolitan area. Some fire chiefs who were asked about this option shuddered at the thought, but we believe their trepidation was caused primarily by the fact that they had never seriously evaluated the risks associated with igniting the cloud, but rather had considered only the consequence of destroying an $80 million ship in a situation in which there might otherwise have been no fire. Clearly, as the flammable cloud gets closer to the city and as the probability of a $1 billion loss becomes larger, the decision to ignite the cloud (and lose $100 million for certain) becomes more attractive from the viewpoint of society at large. We estimate that the fire department (or even military forces) could ignite the vapor cloud or otherwise reduce the loss from Level 6 to Level 5 half the time. Using this estimate, we determine that the annual expected loss from the catastrophic LNG fire would be $2.5 million. This is the dollar amount we add to the 1980-2000 status quo estimates of the marine fire problem to account for the catastrophic LNG fire.

Again, we wish to emphasize that the estimates associated with the Level 6 LNG fire made in this section are only rough estimates, put together in a 1 man-month effort. They are intended primarily to generate discussion and to encourage researchers with expertise in the

LNG area to quantify their judgments so that the best information available can be presented in a form useful to decision makers and to the general public.

With regard to our overall study, this special LNG model adds a relatively small amount to the total marine fire problem (an increase of approximately 3%); more importantly, it does not change the ranking of the alternatives considered because none of them have any appreciable effect on these fires. We have placed the catastrophic LNG fire in the perspective of the entire marine fire problem and confirmed the rather obvious conclusion that a flammable LNG vapor cloud ought to be ignited when there is a high probability that it will otherwise cause a "billion dollar fire." Just how high this probability is depends on society's attitude toward bearing risk.

X DECISION ALTERNATIVES AND COST MODEL

One of the principal purposes of this study was to evaluate the effect of various nationwide programs designed to improve marine fire protection. The model described in the previous chapters represents current and future ship fire losses in the event that none of these programs is initiated; however, the model has been designed with sufficient flexibility so that it can be used to calculate future ship fire losses if one or more of the programs is initiated.

This chapter serves three purposes. First, we define the proposed alternative marine fire protection programs. In defining these alternatives, we provide only the level of detail required to distinguish the cost-effectiveness of the proposed alternatives; once the most cost-effective alternatives are identified, they can be described in more detail and refined with a comprehensive plan for implementation. Second, we indicate how the model incorporates the improvements in fire prevention and fire suppression of each program; this step is analogous to making the changes required in going from Figure I-5 to I-6 in the introductory tutorial example. The model then determines the losses expected from ship fires under each of the proposed programs. Third, we describe how costs of implementing each of the proposed programs are estimated; the costs here are incremental costs relative to the status quo alternative, 1980-2000.

The time span considered is the 20-year period from 1980 to 2000. The programs considered often involve initial costs or other unevenly spaced costs; the ship fire losses also vary from year to year because of changes in the ship population. To provide a uniform basis of comparison, these costs and losses are transformed into an equivalent stream of equal annual payments. The time value of money was taken into account in this conversion; an after-inflation interest rate of 5% was used (costs using a 10% rate are given in Appendix B). It should be noted that all costs and savings are stated in 1975 dollars and that the interest rate quoted is a real interest rate in constant dollars.

Detailed consideration is given in this report to the analysis of nine alternatives:

Maintain Status Quo in Marine Firefighting.

Regional Marine Firefighting Teams (Seattle plan).

Training of Chiefs of Municipal Fire Departments in Marine Firefighting Strategy (Fire Chief Expertise plan).

Training of Firefighters of Municipal Fire Departments in Marine Firefighting Skills (Fire Department Low Level Marine Firefighting Training plan).

Establishment of Marine Firefighting Auxiliary Units in the United States Coast Guard Reserve (Coast Guard Reserve plan).

Training of Ship Officers in Firefighting Strategy (Ship Fire Officer plan).

Instruction of Ship Officers in Use of Built-in CO_2 or Halon Fire Suppression Systems.

Redesign of Built-in CO_2 or Halon Fire Suppression Systems on U.S. Flag Ships.

Installation of Spray Collars on Joints of High-Pressure Lines in Engine Rooms of U.S. Flag Ships.

As discussed in Chapter III, a number of other programs were considered in the course of the research described in this report. Preliminary analysis showed that some of these programs had little or no effect on the marine fire problem, and hence required no further analysis. Other alternatives we had considered were actually adopted during the period of our research, and hence became part of the status quo base case. Finally, many alternatives can be analyzed as variations of the programs considered, with basically the same cost-effectiveness. The remainder of this chapter describes in detail each of the alternatives listed above.

Maintain Status Quo in Marine Firefighting

One of the obvious alternatives for dealing with the marine fire problem is to institute no new programs, and to maintain the status quo level of marine fire protection. This alternative is the Status Quo, 1980-2000. It incorporates the Status Quo, 1975 and the new trends in shipping and new programs in marine fire protection that are already being or will soon be implemented (listed in Chapter II). These new trends and programs will affect marine fire losses independently of any of the programs we are evaluating.

Description of Alternative in Model--All the parameters in the Fire Scenario, Firefighting Performance, Damage, and Value Models of Chapters VI-IX characterize this status quo base case.

Cost of Alternative--As explained in Chapters I and IV, we are computing the expected net savings of each alternative, where expected net savings is expected reduction in loss (relative to the status quo) minus expected increase in cost (relative to the status quo).

Obviously, the expected increase in cost of the status quo alternative, relative to the status quo, is zero.

Regional Marine Firefighting Teams (Seattle plan)

This alternative is the nationwide implementation of the pilot program that originated in Seattle, Washington, under a grant from the Maritime Administration; this alternative has been proposed to Congress in H.R. 11459. The program would provide regional teams of professional firefighters with expertise in marine firefighting. The plan includes the following provisions:

- The United States would be divided into five areas: North Atlantic Coast, South Atlantic Coast, Gulf Coast, Pacific Coast, and Great Lakes and Rivers. Each of these areas would have an administrative office composed of a regional director, an assistant for prefire planning, an assistant for firefighting, an administrative assistant and two secretaries.
- Teams of five men each (one captain, one lieutenant, and three firefighters) would be provided in up to 30 U.S. port cities. These teams are members of the fire department of the city in which they are based, but are employed full time in marine fire protection.
- Each team has a specialized equipment cache consisting of firefighting appliances, foam, special instruments, and equipment for lighting, communications, and transportation. In addition, there is one high-capacity turbine pump in each of the five regions.
- Prefire plans for ships visiting U.S. harbors are prepared by the regional teams and are distributed to all U.S. ports that are visited by the vessel.
- Firefighting training for merchant seamen is to be provided by these regional teams.
- A national data center for ship fires is to be established.

The prefire plans mentioned above consist of binders containing detailed descriptions of the fire suppression equipment aboard the ship, the various compartments of the ship and access routes to these compartments, and the special firefighting problems that may arise. The plans are divided into standardized sections, and they contain photographs of the most important control devices for the ventilation system, fuel pumps, and fire suppression equipment.

The strength of the Seattle plan is that a few men can supply a 100-mile diameter region with expertise in fighting ship fires. Because

these men are members of fire departments, and because they will become known to members of the fire departments within their areas, they will be able to give advice that is accepted by the fire department officers in command of fighting a ship fire; if necessary, they can assist in the actual firefighting. Furthermore, because they have the prefire plans of the ship, they can give advice by radio to help a ship crew fight a fire at sea; if the ship is near enough to land, they can bring equipment by helicopter to aid in fighting the fire.

The expertise of this firefighting team is gained through 250 hours of training that includes the following subjects: ship construction and classification (24 hours); ship familiarization field trips (24 hours); manifest reading (3 hours); report writing (3 hours); boarding and abandoning ship (6 hours); vessel machinery space hazards (9 hours); shipboard fire protection systems, fire mains, CO_2 flooding systems, fixed-foam systems (21 hours); ship stability (6 hours); special firefighting equipment (9 hours); ship firefighting tactics (12 hours); hull and pipe damage control (6 hours); operational team drills (15 hours); naval damage control school (40 hours); helicopter deployment operations (3 hours); ship systems (9 hours); marine chemistry (3 hours).

This initial training is supplemented by 40 hours of annual group retraining, by in-service training, and by the constant review of ship knowledge that will be involved in the preparation of prefire plans.

Description of Alternative in Model--To compute the expected reduction in loss from the Seattle plan, we change the status quo model to reflect the impact of this new alternative. The effect of the Seattle plan type of expertise in fighting a ship fire was directly assessed in Figure IX-5. The transition probabilities in Figure IX-5 indicate the ability of this team to contain and extinguish a fire at its initial level of involvement. However, a detailed assessment must be made on a port-by-port basis to determine the percentage of ship fires in which the expertise of the Seattle team members would be effectively utilized. These new probabilities of the expertise branch distinguish the Seattle plan from the status quo alternative.

Experts in marine firefighting estimated that a team could effectively cover the region within 50 miles of the port in which the team is based. For ship fires within this region, it was estimated that at least 2 members of the Seattle team will be physically present at a ship fire and be listened to by the fire department captain or chief in command of the fire 85% of the time; we estimate their advice would be ignored in the remaining 15% of the fires. In all fires in the 50-mile radius, the fire will be fought by firefighters who have low level training provided over the years by the Seattle plan teams. Using this estimate in the model, we evaluated all port areas of the United States to determine in which ports a five-man team could be expected to reduce losses by more than its cost (see below). As the result of this

procedure, we determined that the optimal Seattle plan consists of 24 teams located in the following port areas (see Figure III-1):

Portland, ME
Boston
New York
Philadelphia
Baltimore
Norfolk
Jacksonville
Tampa
Mobile
New Orleans
Baton Rouge
Beaumont
Houston
Corpus Christi
Duluth
Chicago
Detroit
Cleveland
St. Louis
Los Angeles
San Francisco
Portland, OR
Seattle
Honolulu

These ports handle 83.7% by tonnage of U.S. shipping. Teams in two more port areas, Charleston, South Carolina and Wilmington, North Carolina would be approximately at the break-even point; Valdez, Alaska and Miami, Florida may soon be in the same position.

The remaining 16.3% (by tonnage) of the ports are divided in the following way: 6% are too small or too remote to receive any expertise or training from the regional teams; the remaining 10.3% will have low level training of firefighters supplied over the years by the nearest regional team and, in the 35% of ship fires that are cargo space fires, there will be time for a member of the nearest Seattle team to arrive on scene and provide expertise in fighting the fire. In summary, the status quo probabilities for the different types of leadership of the firefighting team in Figure IX-8 are replaced by

	$\underline{ET}$	$\underline{E}T$	$E\underline{T}$	ET	ST
Land-based forces	0.06	0.193	0	0	0.747

It is estimated that for engine room and cargo space fires, radio-based assistance for fires at sea would give ship officers without expertise in fighting fires a 10% increase in the probability that they

use the built-in system correctly; there would be no change in the outcome of superstructure fires at sea because, by the time effective radio contact was made, the ship's radio would probably be destroyed or out of reach.

Helicopter aid is applicable only for ship fires near land. To deliver useful assistance by helicopter, there must be good weather and the team must be transported to the ship before the major damage is done. Accounting for these factors in each type of fire, we estimated a 5% additional probability of preventing a Level 4 engine room fire from developing into a Level 5 fire and, for cargo fires, a 2% additional probability of preventing a Level 3 fire from becoming a Level 4 fire, and an 11% additional probability of preventing a Level 4 fire from becoming a Level 5 fire.

The above estimates apply to freighter, container, tanker, and passenger ships and to tank barges. Some fishing boats and tug or towboats are sufficiently complex that ship firefighting expertise could have an effect; it is estimated that the Seattle plan would reduce losses by 2% on these smaller vessels. For the dry cargo barges and miscellaneous craft, the structure of the boats is simple enough that expertise in ship firefighting gives no advantage and thus no reduction of loss.

Finally, concerning the fifth and sixth elements of the plan, our analysis indicates that the regional teams would have neither the facilities nor the time to train any significant number of merchant seamen in hands-on firefighting. Our recommendations concerning the national data base are presented in Appendix D.

Cost of Alternative--Most of the cost estimates for the nationwide implementation of the Seattle plan are based on information furnished in the report on the Seattle plan prepared by the Seattle Fire Department and the Washington State Commission for Vocational Education. The following items are annual costs:

Each Regional Administrative Center

Salaries	$137,805
Office costs	12,800*
Administrative travel	28,000*
Total	$178,605 each center

* Estimated by SRI International.

Each Five-Man team

Salaries	$110,513 each team

In addition, the Temple, Barker, and Sloane projections of future U.S. maritime trade show that there will be 976 vessels a year that will require prefire planning over the next 20 years; this includes existing vessels and vessels to be constructed. At $820 per prefire plan, the cost per year is

Prefire plans	$800,320

Finally, there are annual expenses for training and equipment:

Training per team

First year	$ 4,355
Subsequent years	3,261

Equipment per team

First year	$125,368
Subsequent years	10,556

High-capacity turbine pump per region

First year	$150,000

When these costs are reduced to equivalent annual payments over 20 years at an interest rate of 5%, the annual cost is as follows:

Annual Cost of Seattle Plan

Regional Administrative Centers, 5 @ $178,605/year	$ 893,025
Teams (salaries and training), 24 @ $113,862/year	2,732,688
Equipment caches, 24 @ $20,616/year	494,784
Regional, high-capacity pumps, 5 @ $12,036/year	60,180
Prefire plans, 976/year @ $820/year	800,320
Total	$4,980,997

Training of Chiefs of Municipal Fire Departments in Marine Firefighting Strategy (Fire Chief Expertise plan)

Another way to provide expertise in fighting ship fires is to teach a number of battalion chiefs in municipal fire departments the strategy and tactics useful in marine firefighting. The primary difference between this alternative and the Seattle plan is that, after the initial firefighting instruction, the fire department officers return to regular duty. They do not have the constant exposure to the ship fire problem that the full-time Seattle plan ship fire teams have; on the other hand, they are free to perform regular firefighting duties. The specific plan considered includes the following elements:

- Fire department battalion chiefs and, if the area warrants it, deputy chiefs are sent to fire schools to acquire expertise in fighting ship fires. These chiefs return to normal full-time duty in the fire department, but are recognized in the department as ship fire experts; dispatchers are instructed to summon these experts to all ship fires in that municipality or in nearby municipalities with which they have mutual aid agreements. As mentioned in Chapter III, most of the fire chiefs we interviewed felt that battalion chiefs were the most appropriate officers for this assignment. In each port city, the chief of the fire department should have the discretion to select the officers to participate in this program (whether they be chiefs or captains) and should vest in them the authority to act as official advisors in any ship firefighting effort.

- These fire department chiefs receive instruction consisting of 120 hours of course work and ship familiarization in a specialized marine firefighting school. A suitable curriculum for such a program would consist of courses on: Ship Structure (compartments, equipment, structural integrity, interpretation of plans) (80 hours); Ventilation Control (8 hours); Control of Fuel and Electrical Systems (8 hours); Fire Suppression Tactics (prefire plans, ship-based equipment, land-based resources) (24 hours). This training would be supplemented by a 40-hour refresher course each year. It is estimated that, because of promotion, turnover, and retirement, fire department officers would stay in this program an average of 5 years.

- In small port cities, three such battalion chiefs would be needed, one for each shift. In larger port cities, estimates of the number of chiefs needed were made on a port-by-port basis, taking into account the geography of the port area.

- A cache of specialized equipment is provided to each port city under the plan. The composition of this cache is the same as that for each team in the Seattle plan. In addition, five high-capacity turbine pumps are provided for, one in each region of the United States, as in the Seattle plan.

- There is almost universal agreement that some form of prefire plan is of great aid in fighting ship fires. For this reason, this alternative specifies that a simple prefire plan be prepared, perhaps by the U.S. Coast Guard or the American Bureau of Shipping, and distributed to all fire departments in ports at which the ship customarily calls. This prefire plan is simpler than the prefire plan included in the Seattle plan; it can be prepared from readily available documents such as the existing prefire plan aboard the ship, the instructions in the CO_2 or halon equipment room, the Chief Engineer's plans, and the ship's blueprints. It should include layout diagrams of the ship, information on the volume of compartments and the amount of CO_2 required to flood them, and the location of the fire suppression equipment and the fuel, ventilation, and electrical controls.

Description of Alternative in Model--To compute the expected reduction in loss from the Fire Chief Expertise plan, we change the status quo model to reflect the impact of this new alternative. The effect of this combination of fire department expertise, simplified prefire plans, and specialized equipment has been directly assessed in Figure IX-5 under the heading E (expertise). However, the probability that this expertise is present and utilized at a ship fire must be estimated. Because of vacations, sickness, and change of assignments and shifts, there is a possibility that such a battalion chief would not be present at a ship fire; even if he were present, there is the possibility that his advice would not be heeded by the officer in command of fighting the fire. When these factors are taken into account, it is estimated that a specially trained battalion chief would be present and effective at 90% of the ship fires in the port cities covered by the plan.

The model has been used to estimate the program's effect on the reduction in losses attributable to ship fires in individual U.S. ports; the cost of the program (see below) is small enough that it would be cost-effective in all but the smallest U.S. ports. For the purpose of comparison, the plan is analyzed as being implemented in all the areas affected by the Seattle plan. These areas include the 24 cities in which the Seattle plan regional teams would be located, all ports within the 50-mile effective striking distance covered by the teams, and port cities beyond the 50-mile limit where the teams would provide in-service marine firefighting training for the municipal fire departments. This

area of coverage includes the following 68 individual port municipalites:

Atlantic Coast

Portland, Me.
Boston, Ma.
Providence, R.I.
New Haven, Ct.
New York, N.Y.
Hoboken, N.J.
Jersey City, N.J.
Bayonne, N.J.
Newark, N.J.
Elizabeth, N.J.
Linden, N.J.
Carteret, N.J.
Perth Amboy, N.J.
Philadelphia, Pa.
Paulsboro, Pa.
Marcus Hook, Pa.
Camden, N.J.
Gloucester, N.J.
New Castle, De.
Baltimore, Md.
Norfolk, Va.
Newport News, Va.
Wilmington, N.C.
Charleston, S.C.
Savannah, Ga.
Jacksonville, Fl.
Miami, Fl.
San Juan, P.R.

Gulf Coast

Tampa, Fl.
Mobile, Al.
Pascagoula, Ms.
New Orleans, La.
Lake Charles, La.
Beaumont, Tx.
Port Arthur, Tx.
Galveston, Tx.
Texas City, Tx.
Houston, Tx.
Freeport, Tx.
Corpus Christi, Tx.

Great Lakes and Rivers

Duluth, Mn.
Escanaba, Mi.
Chicago, Il.
Indiana Harbor, In.
Gary, In.
Detroit, Mi.
Toledo, Oh.
Cleveland, Oh.
Conneaut, Oh.
Buffalo, N.Y.
Pittsburgh, Pa.
Huntington, W.V.
Cincinnati, Oh.
St. Louis, Mo.
Memphis, Tn.
Baton Rouge, La.

Pacific Coast

Seattle, Wa.
Tacoma, Wa.
Portland, Or.
Coos Bay, Or.
San Francisco, Ca.
Oakland, Ca.
Richmond, Ca.
Los Angeles, Ca.
Long Beach, Ca.
Valdez, Ak.
Anchorage, Ak.
Honolulu, Hi.

If the Fire Chief Expertise plan was implemented in these 68 municipalities, the status quo probabilities for the leadership of the firefighting team in Figure IX-8 would be changed as follows:

	ET	ET	ET	ET	ST
Land-based forces	0.133	0.015	0.66	0.132	0.06

As in the Seattle plan, it is estimated that this plan would cause a 2% reduction in fire losses in fishing boats and on tugs and towboats.

Cost of Alternative--A city-by-city consideration of the ports covered by the plan shows that 298 fire department battalion chiefs would be sufficient to cover adequately all shifts in the port areas.

Each chief attends 3 weeks of marine fire school the first year and a 1-week refresher course each subsequent year; with an estimated 5-year turnover in the program, this yields 7/5 weeks of schooling per year per chief. The costs per individual for a week of these courses are estimated as follows: salary compensation of $577/week ($30,000/year) corresponding to the average rank of battalion chief; per diem expenses of $263/week ($37.50/day); tuition charge of $312/week, the charge applicable at Texas A&M for marine fire training for the tankerman rating (because this program is not subsidized, the tuition costs should reflect the true cost of training); transportation costs of $212/year, the average roundtrip air fare to any one central marine firefighting school in the United States.

Annual cost of training one battalion chief

Salary	$ 808
Per diem	368
Tuition	437
Transportation	212
Total	$1,825

The cost of preparing and distributing the simplified prefire plans is estimated at $100 per ship; as discussed under the Seattle plan, there would be 976 plans per year to be prepared and distributed. The cost of the equipment caches is also discussed under the Seattle plan.

Annual cost of Fire Chief Expertise plan

Marine Fire Schools, 298 officers @ $1,825/year	$ 543,850
Prefire plans, 976/year @ $100 each	97,600
Equipment caches, 65 cities @ $20,616/year (8 neighboring New Jersey cities share 5 caches)	1,340,040
Regional, high-capacity pumps, 5 @ $12,036/year	60,182
	$2,041,672

Training of Firefighters of Municipal Fire Departments in Marine Firefighting Skills (Fire Department Low Level Marine Firefighting Training plan)

A different type of alternative involves familiarizing firefighters with ships. Firefighters are often totally unfamiliar with ship

structure; they do not know the location of ship compartments and engine rooms, the structure of ladders and doorways, the general appearance and location of ventilation systems, and the availability and capability of built-in fire suppression systems. Even the aid of ship officers and crew members is often ineffective, because the firefighters are not familiar with nautical terminology. The alternative proposed to remedy this situation is:

- o Firefighters likely to respond to ship fires would receive 40 hours a year (preferably 20 hours each 6 months) in-service training in marine firefighting. The emphasis in these training sessions would be on ship familiarization acquired through inspection of ships. This training could be supplemented by audiovisual instruction.

Description of Alternative in Model--To compute the expected reduction in loss from the Fire Department Low Level Training plan, we change the status quo model to reflect the impact of this increased marine firefighting training. The implications of the training program have been assessed in Figure IX-5 under the heading T (training). This plan has been optimized by considering the reduction in losses attributable to ship fires that would be expected in individual ports; the cost of the program (see below) is small enough that it is cost-effective even in very small ports. For purposes of comparison, the plan is analyzed as being implemented in the same cities as in the Fire Chief Expertise plan. It is estimated that adequate coverage for all shifts in the port areas would be achieved by training two companies for each battalion chief in the Fire Chief Expertise plan: this yields a total of 2 x 298 = 596 companies to be trained. The effect of this program is represented by replacing the status quo probabilities of the level of training of the firefighters in Figure IX-8 by

	$\underline{ET}$	$\underline{E}T$	$E\underline{T}$	ET	ST
Land-based forces	0.13	0.64	0.02	0.15	0.06

Cost of Alternative--Because the training is performed while the firefighters are on duty, the only additional cost of the alternative is that of the instructors. A base salary of $26,000/year per instructor (equivalent to the level of fire department captain) is used. Each instructor can give instruction in 40 1-week sessions each year; each session is attended by two fire department companies. In addition, each instructor must spend 2 weeks each year in refresher courses on ship firefighting; the weekly tuition, travel and per diem costs for these courses are the same as those in the Fire Chief Expertise plan in the previous section.

Annual Cost of one instructor conducting
40 1-week training sessions per year

Salary	$26,000
Per diem, 40 weeks @ $250/week	10,000
Transportation, 40 weeks @ $150/week	6,000
Training, 2 weeks/year	1,362
Total	$43,362

Because 596 companies must be trained, 2 at each session, a total of 298 sessions are required per year with a total of 7.45 instructors (full-time equivalent). Hence, the annual cost of this plan is:

Annual cost of Fire Department Low Level Marine Firefighting Training plan	$323,047

Establishment of Ship Firefighting Auxiliary Units in the United States Coast Guard Reserve (Coast Guard Reserve plan)

The final alternative relying on land-based firefighting forces is the establishment in the Coast Guard Reserve of units of professional firefighters to provide marine fire protection. A program of this type is already in effect in the Los Angeles-Long Beach area, and the alternative proposed here would extend it nationwide. This program resembles the Seattle plan in that it involves regional teams of professional firefighters; because Coast Guard Reserve units function only several days a month, however, the teams would not maintain the same high level of expertise in ship firefighting as the full-time Seattle plan teams. The structure of the alternative proposed here is

- o Establishment of 15-man units in the U.S. Coast Guard Reserve. These units would consist of professional firefighters who could give advice to municipal fire departments in fighting ship fires and, when appropriate, assist in fighting the fire. These units would also be able to give assistance by radio to ships at sea and to give aid by helicopter to ships near land.
- o For purposes of comparison, units are established in the same 24 locations of the optimized Seattle plan.
- o Each unit has the same cache of equipment as each regional team in the Seattle plan. The units also have available the same five high-capacity turbine pumps.

- o Simplified prefire plans are prepared and distributed, as in the Fire Chief Expertise plan.
- o Training of these units would consist of 2 weeks in ship firefighting training at a firefighting school when men join the unit. These professional firefighters could maintain their specialized ship knowledge and skills by drills during their reserve duty. It is estimated that men will remain with the unit an average of 5 years.

Description of Alternative in Model--As in the Seattle plan, these 24 units, each with an effective 50-mile striking distance, cover 83.7% (by tonnage) of U.S. shipping. Because the units have limited time to devote to ship fire protection, they will have no effect on the 16.3% of shipping outside their territories. For the ports within their effective striking distance, it is estimated they will be physically present at the ship fire and listened to by the fire department chief in command of the fire 80% of the time. In these cases, it is estimated that the units will add expertise (E) to the firefighting effort when this is lacking. Hence, the status quo probabilities of the different types of leadership of the firefighting team in Figure IX-8 are replaced by

	$\underline{E}\underline{T}$	$\underline{E}T$	$E\underline{T}$	ET	ST
Land-based forces	0.262	0.023	0.471	0.184	0.06

For radio assistance for ship fires at sea, for helicopter and radio assistance for ship fires near land, and for fires aboard fishing boats, tugs, and towboats, it is estimated that this alternative will have the same effect as the Seattle plan.

Cost of Alternative--Each of the 15 men per unit would receive initially 2 weeks of training and it is estimated that each man would remain with the unit an average of 5 years. During the 2-week initial training period, taken on vacation time, each firefighter would be paid according to his fire department salary. All other time in the program is part of reserve duty. It is assumed that only one-half of the Coast Guard Reserve unit of 15 men would represent additional hiring; the additional men could be displaced from other Coast Guard Reserve duties.

Annual cost of 1 Coast Guard Reserve unit of 15 men

Coast Guard Reserve salary, 7.5 men @ $1,250/year	$ 9,375
Training, 15 men @ $450/year	6,750
Equipment cache	20,616
Total	$36,741

Annual Cost of Coast Guard Reserve plan

Coast Guard Units, 24 @ $36,741/year	$ 881,784
Prefire plans, 976/year @ $100/year	97,600
High-capacity pumps, 5 @ $12,036/year	60,180
Total	$1,039,564

<u>Training of Ship Officers in Firefighting Strategy (Ship Fire Officer plan)</u>

With the expected requirement of 1 week of firefighting training every 5 years for all merchant seamen (see Chapter IX), the psychological preparedness and firefighting skills of ship crews will be markedly improved in the years 1980-2000. An alternative that will further improve the ability of ship-based forces to fight ship fires is the training of officers on U.S. flag ships in firefighting strategy and leadership. This alternative has the following elements:

- Two officers (deck and engineering officers) on each of the 700 U.S. flag merchant ships will be required to complete 1 extra week of firefighting training, thus extending the required training for these officers to 2 weeks every 5 years. These extra 40 hours of instruction will concentrate on detailed knowledge of the operation of built-in fire suppression systems, on setting fire boundaries, and on the various aspects of organizing a firefighting squad aboard a ship. In addition, these officers will be required to complete a 16-hour refresher course each year; this could be administered locally by unions, shipping companies, or the Coast Guard, perhaps with the aid of preprogrammed audiovisual material.

<u>Description of Alternative in Model</u>--For fires fought by ship-based forces, the effect of the expertise acquired by these officers is estimated in Figure IX-5 under the label E (expertise). For cases in which land-based forces fight the fire, it is estimated that the presence and advice of such a ship officer could bring effective expertise to the land-based forces in 10% of the cases in which it is not already present. For these fires fought by land-based forces, however, it must be remembered that the Ship Fire Officer plan affects only U.S. flag ships; the statistics of U.S. versus foreign flag ship fires are presented in Chapter VI. When these factors are taken into account for the Ship Fire Officer plan, Figure IX-8 is replaced by

<u>Firefighters</u>	<u>Ship Type</u>	$\underline{E}\underline{T}$	$\underline{E}T$	$E\underline{T}$	ET	ST
Land-based forces	Freighter	0.59	0.11	0.14	0.10	0.06
	Container	0.62	0.11	0.11	0.10	0.06
	Tanker	0.60	0.11	0.13	0.10	0.06

	Passenger	0.62	0.11	0.11	0.10	0.06
	Tank barge	0.59	0.11	0.14	0.10	0.06
Ship-based forces	Freighter	0.00	0.00	0.09	0.91	--
	Container	0.00	0.00	0.09	0.91	--
	Tanker	0.00	0.00	0.00	1.00	--
	Passenger	0.00	0.00	0.05	0.95	--
	Tank barge	0.00	0.00	0.01	0.99	--

In addition, these officers will normally organize firefighting squads and will conduct fire drills on their ships. These drills are expected to eliminate 16% of bad initial responses of the crew. As mentioned earlier, this improvement is less for fires in harbor or at dock, because there fires can occur on foreign flag ships where the program has no effect.

Cost of Alternative--Because the initial training is a continuation of the required fire school (in the status quo, 1980-2000) and because the refresher course is taken locally, there are no transportation costs. The average time each officer spends in training is 0.36 weeks per year; with tuition at $312/week, per diem at $263/week, and salary at $600/week (representative of the wage of a 2nd deck officer or engineer), the average cost of training an officer would be $423/year. The number of officers required is two for each of the 700 U.S. flag vessels; if this figure is increased to take into account vacation time and turnover, an estimated 3500 officers would have to be trained. The annual cost of this plan is:

Annual cost of Ship Fire Officer plan	$1,480,500

Instruction of Ship Officers in Use of Built-in Fire Suppression Systems

Built-in fire suppression systems, if used correctly, are very effective in fighting ship fires. Because the system is rarely if ever used on any given ship, it is easy for the ship officers to forget the sequence of procedures necessary for the proper use of the system. These procedures include correct utilization of the fire detection and location equipment, securing of ventilation, correct deployment of the complicated CO_2 or halon release mechanism, and waiting for the compartment to cool before opening. The following program, simpler than the Ship Fire Officer plan, is proposed to correct this situation on U.S. and foreign flag ships (the latter when in U.S. ports).

- Twenty-four instructors are provided in major port areas of the United States. These individuals instruct and certify officers on each ship (U.S. flag and foreign flag) that visits U.S. ports. The instruction is solely in the

correct method of utilization of the built-in system on that particular ship.

- o The instructors themselves receive 1 week of training per year at a marine fire school.

Description of Alternative in Model--We estimate that there is an 80% chance that the instructor would succeed in getting aboard the ship and scheduling instruction with the relevant ship officer; we estimate that there is then an 85% chance that he succeeds in communicating effectively with him (foreign ships are included). For ship fires at sea, we estimate a 75% chance that when the fire occurs, the ship officer will remember what he was taught; for fires at dock or in harbor, where foreign flag ships visiting U.S. ports less frequently are included, this probability is reduced to 65%. Taking into account each of these estimates and the rotation of ship officers, we estimate a 56% reduction at dock and in harbor and a 49% reduction at sea and near land in the number of times that the built-in system is used incorrectly or that the decision is made not to use the system.

Cost of Alternative--The only cost of this program is the instructors' salaries and training costs. Each instructor's salary is estimated at $20,000/year, the average salary and benefits for a firefighter. The cost of training is based on the same estimates used in previous alternatives. The annual cost of the alternative is therefore:

Annual Cost of Instruction of Ship Officers in the Use of Built-in Systems

Salaries, 24 @ $20,000/year	$480,000
Training, 24 @ $787/year	18,888
Total	$498,888

Redesign of Built-in Fire Suppression Systems on U.S. Flag Ships

A second alternative aimed at increasing the likelihood of correct use of the built-in CO_2 or halon fire suppression system is the redesign of the system itself. This redesign alternative would apply to U.S. flag ships only. In the redesigned system, the pulling of a single lever would secure the ventilation and deliver agent to the selected compartment. The controls of the fire detection and location system, the ventilation system and fuel pump, and the built-in fire suppression system would be integrated in a single panel. The numerous levers and switches that are now required to deliver agent to a given compartment would be linked together electronically and activated by a single lever.

Description of Alternative in Model--Given that a redesigned system is in place, we estimated that in the case of a ship fire, the command decision to use it would be made 93% of the time, and when deployed, this sophisticated system would work correctly 90% of the time. For the 10% of the time that it malfunctions, the ship officer would attempt to deploy the system manually. In this latter case, the probability of successful use in Figure IX-5 would still hold.

Cost of Alternative--Morris Guralnick Associates have estimated that redesigning the built-in systems as described would cost approximately $20,000 for the engine room and $60,000 for the dry cargo holds of a ship. There are 700 U.S. flag ships that would require the redesign initially, and 500 new U.S. flag ships that are expected to be constructed in the period 1980-2000; all of these ships would require the new, redesigned systems in the engine rooms. The figures for freighter, container, and passenger ships imply that the new, redesigned system would be placed in dry cargo holds on 465 ships initially and on 332 ships to be constructed in the years 1980-2000. The annual costs of this alternative are given below.

Annual cost of redesigning built-in systems on U.S. flag ships

Engine rooms	$1,620,000
Dry cargo holds	3,100,000
Total	$4,720,000

Installation of Spray Collars on Joints of High-Pressure Lines in Engine Rooms of U.S. Flag Ships

The final individual alternative analyzed in this report is the installation of spray collars on joints of high-pressure fuel, lubrication oil, and hydraulic fluid lines in the engine rooms of all U.S. flag freight, container, tank and passenger ships. These spray collars would reduce the chance that a failure at a joint of a pressurized flammable liquid line would cause a spray that could come into contact with a hot surface and ignite. It would also reduce the possibility of a spray-formed aerosol causing an explosion. Spray collars are currently being installed on U.S. Navy ships.

Description of Alternative in Model--Marine fire experts have estimated that spray collars are 100% effective in preventing spray fires and explosions from failures at joints on which they are properly installed, and are 50% effective when not properly installed. Based on information from the Navy, we estimate that the collars would be properly installed 75% of the time; the 25% of the collars improperly installed result from the periodic removal of the collars for fuel

line maintenance and their subsequent re-installation. Thus, on the average, they are (0.75 x 1.0) + (0.25 x 0.5) = 87% effective in preventing fires and explosions from sprays at joints of high pressure flammable liquid lines.

In the past, these sprays have caused 52% of all engine room fires. Of this 52%, 86% were rapidly-burning fires and 14% were explosions. For the 48% of engine room fires not caused by such sprays, 62% were rapidly-burning fires and 38% were explosions. If we assume that the same types of engine room fires will occur in the future as have occurred in the past, we can use the estimates above and the probabilities presented in Figure VI-1 to calculate the expected preventive effect of spray collars. The result of the calculation is a 6% reduction in the number of explosions and a 39% reduction in the number of rapidly-burning fires in engine rooms. These reductions apply only to U.S. flag ships (where the spray collars would be installed) and therefore are used in the Fire Scenario Model only for ships at sea. For ships at dock and in harbor, the percentage reduction in engine room fires is less since foreign flag ship fires are also included in these locations. The percentage reductions above are used for U.S. flag ships at dock and in harbor, whereas the status quo, 1980-2000 figures are used for foreign flag ships in these locations.

Cost of Alternative--There are 700 U.S. flag merchant ships currently in operation, and 500 more U.S. flag merchant ships are expected to be built during the years 1980-2000. Under the Spray Collar plan, each of these ships would be fitted with spray collars in the engine room. Based on information from the Navy, we estimate that the Spray Collar plan, as outlined above, would cost $1,000 per ship for the initial installation and $100 per year per ship for maintenance. We wish to emphasize that these cost figures are rough estimates; the Navy is currently conducting a study of its spray collar program, so better cost estimates should soon be forthcoming. Based on the estimates above, the equivalent annual cost of the Spray Collar plan, amortized over the period 1980-2000, is:

Annual Cost of Spray Collar Plan	$158,000

Combination of Individual Plans

There are 247 possible combinations of the individual plans. The effects of combining individual plans are carefully analyzed in the model to avoid any double counting of savings that overlap. The cost of combined plans is the sum of the cost of the individual elements.

Appendix A

RELEVANT MARITIME INDUSTRY STATISTICS

Appendix A includes a profile of the fleet of ships engaged in U.S. foreign and domestic trade, the percentage of total shipping tonnage by port and by region, and the principal commodities involved in U.S. waterborne commerce.

Table A-1 SHIPS ENGAGED IN U.S. FOREIGN AND DOMESTIC TRADE, 1975*

Ship Type	Number of U.S. Flag Ships	Number of Foreign Flag Ships
General cargo freighters	161	3,834
Dry bulk and neobulk carriers	166	2,536
Containerships, barge carriers, and combination carriers	151	479
Liquid bulk carriers (tankers)	246	1,290
Total	724	8,139

* Estimated from Maritime Administration statistics and World Almanac; excludes military ships and ships traveling exclusively on inland waterways.

Table A-2 MAJOR U.S. PORT PERCENTAGES OF TOTAL TONNAGE* OF U.S. FOREIGN AND DOMESTIC WATERBORNE COMMERCE

__Atlantic Coast__

Portland ME	1.6%
Boston MA	1.5
New Haven CT	0.7
Providence RI	0.5
New York NY Elizabeth, Jersey City, Hoboken, Bayonne, and Newark NJ	11.0
Philadelphia, Marcus Hook, Paulsboro PA; Camden, Gloucester NJ	6.9
New Castle DE	0.7
Baltimore MD	3.4
Norfolk, Newport News VA	4.2
Wilmington NC	0.5
Charleston SC	0.5
Savannah GA	0.6
Jacksonville FL	0.8
San Juan PR	0.7

__Gulf Coast__

Tampa FL	2.3%
Mobile AL	1.9
Pascagoula MS	0.7
New Orleans LA	8.2
Lake Charles LA	0.9
Houston, Galveston, Texas City, and Freeport TX	7.2
Port Arthur and Beaumont TX	3.5
Corpus Christi TX	1.9

__Rivers__

Baton Rouge LA	3.4%
Memphis TN	0.6
St. Louis MO	1.2
Cincinnati OH	0.5
Pittsburgh PA	0.5
Huntington WV	0.7

__Great Lakes__**

Duluth MN	2.3%
Chicago IL	2.6
Toledo OH	1.2
Detroit MI	1.6
Cleveland OH	1.3

__Pacific Coast__

Los Angeles and Long Beach CA	3.5%
San Francisco, Oakland, and Richmond CA	1.4
Portland OR	1.2
Seattle, Tacoma, and Puget Sound ports WA	2.4
Honolulu HI	0.6

---

*Source: Army Corps of Engineers, in World Almanac.

**Some iron ore and stone ports on the Great Lakes with as much as 1% of total tonnage are not listed.

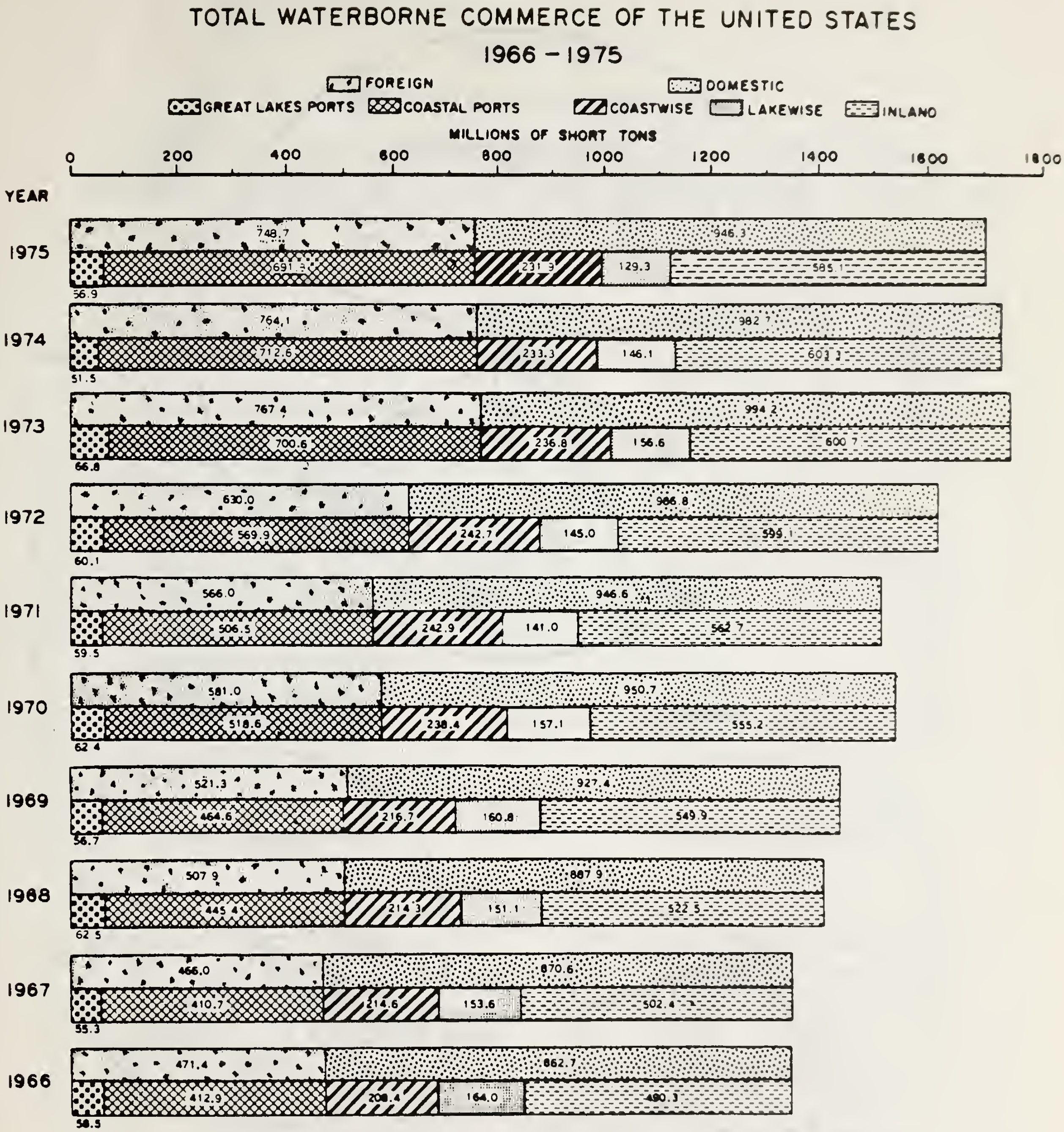


FIGURE A-1 WATERBORNE COMMERCE BY REGION*

*Source: U.S. Army Corps of Engineers

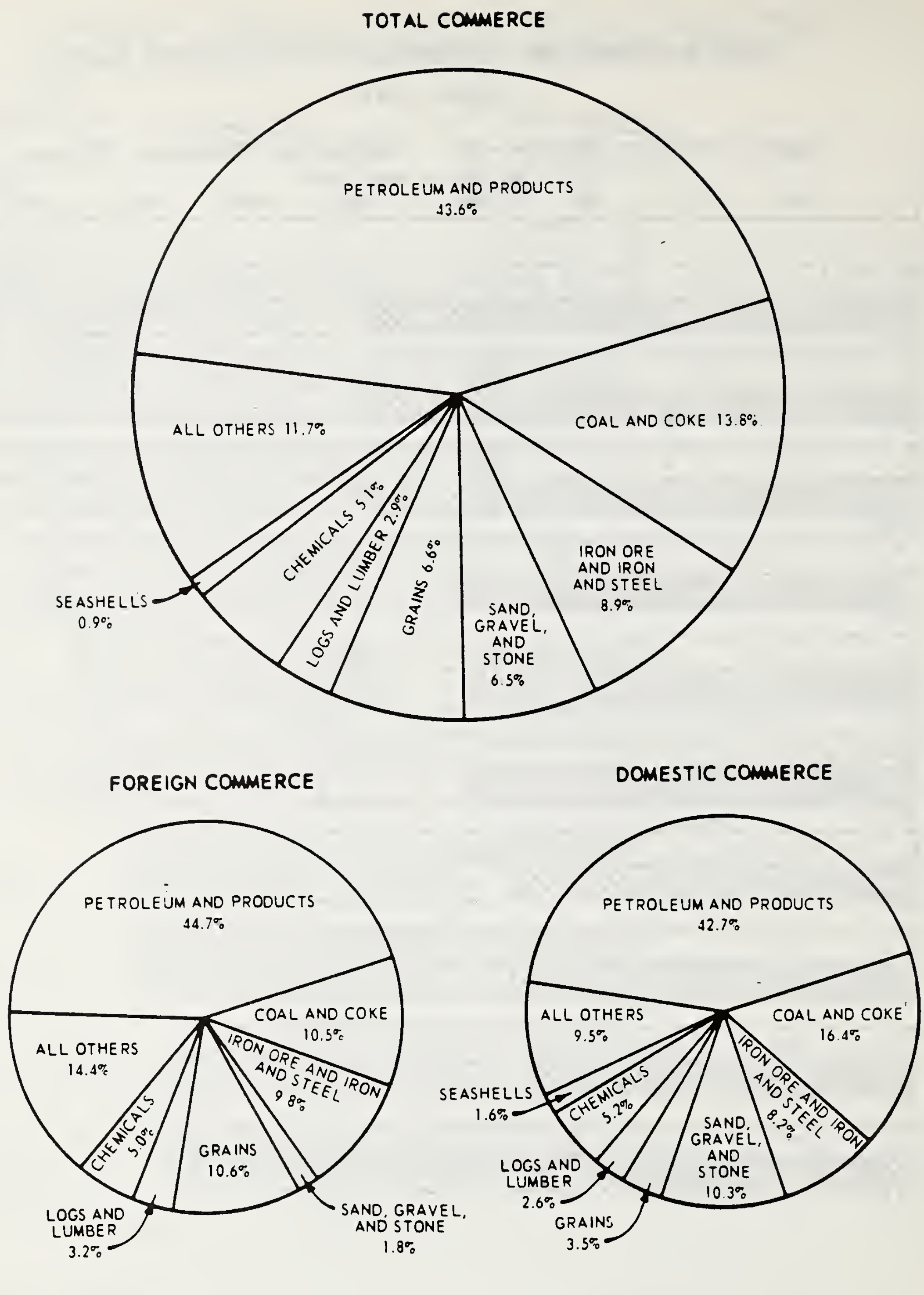


FIGURE A-2 PRINCIPAL COMMODITIES CARRIED BY WATER, 1975*

*Source: U.S. Army Corps of Engineers

Appendix B

SENSITIVITY TO INTEREST RATE

Table B-1 COST-EFFECTIVENESS OF INDIVIDUAL ALTERNATIVES: RANKING BY EXPECTED NET SAVINGS USING AFTER-INFLATION INTEREST RATE OF 10% (MILLIONS OF DOLLARS PER YEAR)

Rank	Alternative	Expected Reduction in Loss	Expected Increase in Cost	Expected Net Savings
1	Fire Chief Expertise	18.1	2.3	15.8
2	Seattle	20.4	5.1	15.3
3	Coast Guard Reserve	15.4	1.1	14.3
4	Fire Department Low Level Training	7.4	0.3	7.1
5	Ship Fire Officer	7.7	1.5	6.2
6	Instruction on Built-in Systems	5.8	0.5	5.3
7	Spray Collars	3.4	0.2	3.2
8	Redesign Built-in Systems	7.9	5.7	2.2
9	Status Quo	0.0	0.0	0.0

Appendix C

NATIONAL TRANSPORTATION AND HAZARDOUS CARGO FIRE EMERGENCY PLAN

A modification of the fire chief expertise component of the optimal program may make the entire program more cost-effective. This modification would broaden the scope of the program to cover all transportation and hazardous cargo fires as opposed to ship fires alone. Fires in ships, trains, and trucks have several common features; therefore, the battalion chiefs or deputy chiefs who are given expertise in fighting fires aboard ships could, at little additional cost, be given expertise at the same time in fighting rail car and tank truck fires that are much more frequent. Arrangements to dispatch these chiefs to all serious transportation and hazardous cargo fires could be made in local fire departments.

Such a program could take advantage of existing organizations and sources of information. It would comprise three elements: training, sources of emergency information, and huge supplies of firefighting equipment and agent.

The training would be coordinated by the NFPCA arm of the new Federal Emergency Management Administration. Under its direction, the National Fire Academy could train the training officers of local fire departments. These training officers would train their local departments in the fighting of transportation and hazardous cargo fires and would also provide such expertise to the officer in command of the fire when an incident occurred.

The second element of the plan, emergency information, would be provided both by telephone and by a simple prefire plan at the scene of the fire. The telephone advice could be provided by extending the Chemical Transportation Emergency Center in Washington, D.C., or the new Chemical Hazard Response Information System to provide information about ships just as it currently does for rail cars, tank trucks, and their cargoes. A simple prefire plan of each ship, prepared either during construction or during a routine Coast Guard inspection, would be distributed to the Coast Guard, the chemical emergency centers, and to local fire departments in ports visited by that ship. This simple prefire plan would mark the location of firefighting equipment aboard the vessel, would show points of access to the different spaces, and would indicate different sets of fire boundaries that could be established.

The third element of the plan is an ample supply of firefighting agent and equipment for the worst transportation fires. By making prior

arrangements with the proper agencies and companies, all the material needed could be promptly supplied. A well organized system for moving the special equipment to where it is needed may reduce the need for all the new equipment proposed in the Fire Chief Expertise plan and thereby increase its cost-effectiveness.

The National Fire Prevention Association, under contract to the U.S. Department of Transportation, has developed a short course of instruction in the handling of transportation-related and hazardous cargo fires. This short course may be useful in developing the more extensive training program for the Fire Chief Expertise plan (described in detail in Chapter X).

Appendix D

SUMMARY OF DATA REQUIREMENTS

Appendix D summarizes the data requirements for this cost-effectiveness study of marine fire protection programs, comments on data items that are likely to be useful for other decisions, and suggests improvements that could be made in the national data bank for ship fires.

First, we indicate whether the Coast Guard records provide adequate data for each of the elements in the decision tree of Figure I-1.

<u>Fire Scenario</u>	
Ship type, flag, size, age, and location	CG*
Fire location and development	CG, E
<u>Firefighting Performance</u>	
Initial response and initial level of fire	CG, E, N
Expertise of leadership and training of firefighters	E, N
Equipment, agent, and use of built-in systems	CG, E, N
<u>Losses</u>	
Extent of damage	CG, E, N
Dollar loss	N (incomplete and inaccurate)

The decision tree itself does not include the specific tactics employed by the firefighters; these tactics were considered in developing the rules describing the ability of the different firefighting teams to contain and extinguish fires at each of the initial levels of involvement. Data items in addition to those included in the decision tree would be useful in choosing specific firefighting tactics, agents, and methods of application, and in designing fire protection equipment. These more detailed data items are listed below, together with an indication of the extent to which they are provided by Coast Guard records.

Fuel, Energy, and Ignition

Ignition source and cause (a cross-reference to fires caused by collision, but classified only in the collision records, would be helpful)	CG
Type of fuel	CG
Amount and geometry of fuel	E, N
Ventilation rate	E, N
Disposition of energy released	N

Fire Behavior

Temporal fire characteristics (rate and buildup)	E
Spatial fire characteristics (compartment involved)	CG, E
Mode of spread beyond compartment of origin (conduction, convection, radiation, or burn along fuel element)	N
Smoke and heat content	N

Fire Detection and Suppression

Method of detection and location	E, N
Who responded initially	CG, E
How fire grew out of control (when relevant)	E
Who brought fire under control	CG, E
Time to bring fire under control	CG, E, N
Principle agent and application equipment	CG, E

As indicated, much of this information is already in the Coast Guard records. These records could be extended, at least for future ship fires, to include the items that are missing. Actual monetary loss is the only item listed above that would be very difficult to obtain (see Chapter II). Since the Coast Guard already investigates ship fires and maintains the national data base for all ship casualties, it seems most reasonable that the Coast Guard continue to maintain the data collection and record-keeping responsibility.

Legend:

CG - Determined from Coast Guard records.
E - Estimated from Coast Guard records.
N - Not obtainable from Coast Guard records.

As indicated, the status of the data varies by ship fire for some of the items listed.

REFERENCES

The list of references is presented in two parts: first, the names of the individuals and organizations who provided information in personal interviews or by telephone; and second, the publications, documents, and sets of statistics that were used in the analysis.

The list of individuals and organizations includes only those people whose information was actually used in the analysis. The list is divided into five sections, in the following order: U.S. Government agencies; insurance, technical, and trade sources, and firefighting schools; port authorities; municipal fire departments; and shipping lines.

U.S. GOVERNMENT AGENCIES

National Bureau of Standards

Mr. Benjamin Buchbinder	Chief, Office of Information and Hazards Analysis

National Fire Prevention and Control Administration

Mr. J. Thomas Hughes	Executive Advisor
Mr. William Overbey	Director, Analysis Division, National Fire Data Center
Mr. Phillip Schaenman	Associate Administrator, National Fire Data Center
Mr. Howard Tipton	Administrator

U.S. Coast Guard

Office of Merchant Marine Safety

Lt. Gerald Abrams	Cargo and Hazardous Materials Division
Cdr. William Ecker	Chief, Information and Analysis Staff
Cdr. Richard Hess	Chief, Personnel Qualification Branch
Mr. Donald Kerlin	Fire Protection Engineer
Lcdr. Lindak	Chief, Hazard Evaluation Branch
Mr. Daniel Sheehan	Technical Advisor

Office of Marine Environment and Systems

Lt. J. Lambert	Vessel Traffic Service
Mr. Donald Ryan	Port Safety and Law Enforcement

Coast Guard Reserves

Chief Larry McPolin	Firefighting Division
Mr. X. Padilla	Firefighting Division

Maritime Administration

Office of Maritime Manpower

Mr. Ed Hackett	Maritime Training Specialist
Mr. Pat Patterson	Maritime Training Specialist

Office of Market Development

Mr. George Sherwood	Trade Specialist, Western Region

Office of Ports and Intermodal Development

Mr. Armour Armstrong	Director
Mr. Richard Black	Program Manager
Mr. William Bovis	Transportation Specialist
Mr. John Carnes	Chief, Central Region

Office of Ship Management

Mr. Charles Johnston	Ship Management Specialist, Western Region
Capt. Carl Otterberg	Ship Management Officer, Western Region

U.S. Navy

Mr. David Kay	Naval Sea Systems Command

American Hull Insurance Syndicate

Mr. Ray Hicks	Claims Manager
Mr. Allen Schumaker	President
Mr. Merck	Assistant Claims Manager

Applied Technology Corporation, Norman, Oklahoma

Dr. J. Reed Welker	Fire Scientist

Aviation Power Supply, Inc.

Mr. R. Chaney	Assistant Vice President

Bar Pilots Association

Capt. Grant	President

Daton T. Brown Co.

Mr. Robert Fisher	Engineer

Calhoun MEBA Engineering School

Mr. Preston Harrison	Firefighting Instructor
Mr. LaDana	Administrator

California Maritime Academy

Mr. John Keever	Head, Nautical Industrial Technology

Dougan, Fader, Reynolds, and Wheeler

Mr. John Frothingham	Average Adjuster

Fireman's Fund Insurance Companies

Mr. John Stewart	Vice President, Marine Insurance

The FPE Group

Mr. Lou Almgren	President
Mr. Bryce Connick	Senior Fire Protection Analyst

Grumman Data Systems

Capt. David Lentz	*

Morris Guralnick Associates, Naval Architects and Engineers, San Francisco

Mr. Norman Harris	Machinery and Mechanical Department Supervisor
Mr. Phil Mannina	Hull Department Supervisor
Mr. Hubert Russell	Assistant Chief Engineer
Mr. Don Yokum	Marketing Manager

MSC Firefighting School, Treasure Island, California

Mr. Dale Krabbenschmidt	Firefighting Instructor

National Maritime Union

Mr. Frank Boland	Director, NMU Upgrading and Retraining Plan

Texas A&M University, Firemen Training School

Mr. John Rauch	Assistant Training Specialist
Mr. Henry Smith	Chief

United States Salvage Association

Mr. R. Calhoun	Chief Estimator
Mr. Donald Gross	President
Mr. Henk van Hammen	Principal Surveyor, Atlantic Coast

PORT AUTHORITIES

Houston Port Authority

Mr. Louis Brown	Chief of Fire Safety

Massachusetts Port Authority

Chief Charles Arena	Airport Fire Department
Assistant Chief W. Don Jeffrey	Airport Fire Department

*Unfortunately, job titles were not obtained from all the people who provided information for this analysis.

New Orleans Port Commission

Cdr. Benson	Fireboat Division
Mr. William Eckert	

Port Authority of New York and New Jersey

Mr. Cornelius Fleming	Assistant General Manger, Marine Operations Division
Mr. Derwood Hall	Manager, New Jersey Marine Terminals

Oakland Port Authority

Mr. Hallert	Inspector

Philadelphia Port Corporation

Mr. Harry Fisher	Secretary

San Francisco Port Commission

Mr. Richard Goldman	Port Commissioner

Port Authority of St. Louis

Mr. William Twyman

MUNICIPAL FIRE DEPARTMENTS

Baltimore Fire Department

Chief H. Catterton	Deputy Chief of Department
Capt. W. Stephens	

Baton Rouge Fire Department

Chief Harold Prevost	Training Director

Boston Fire Department

Chief Paul Cook	Marine Division

Chicago Fire Department

Commissioner Robert Quinn	Commissioner of Department
Lt. Fred Wertz	Marine Rescue Unit

Cleveland Fire Department

Capt. Bishop — Marine Division

Corpus Christi Fire Department

Acting Assistant Chief Shaw

Detroit Fire Department

Chief T. Phillips

Duluth Fire Department

Assistant Chief William Denno

Elizabeth (NJ) Fire Department

Battalion Chief William Neafsey

Everett (WA) Fire Department

Captain J. Maag

Galveston Fire Department

Chief H. O'Donohoe

Honolulu Fire Department

Chief F. Awana — Chief of Training

Jacksonville Fire Department

Chief M. Hendricks — Chief of Training

Long Beach Fire Department

Deputy Chief Thomas Cady

Los Angeles Fire Department

Chief M. Mitchell — Chairman, Harbor Fire Fighting Committee

Mobile Fire Department

Chief Edwards

New Orleans Fire Department

Superintendent William McCrossen	Chief of Department

New York Fire Department

Capt. Theron Bingham	Marine Division
Chief Joseph Flynn	Chief of Department
Battalion Chief Gilbert O'Neill	Marine Division
Chief Thomas Rush	Deputy Chief, Marine Division

Oakland Fire Department

Chief D. Mathews	Chief of Operations

Philadelphia Fire Department

Chief Joseph McCarey	Marine Division
Deputy Fire Marshall J. Maskill	
Assistant Chief James Miller	Research and Planning

Port Arthur Fire Department

Fire Marshall Howard Bourque

Portland (ME) Fire Department

Chief Paul Cook	Marine Division

Portland (OR) Fire Department

Chief Vern Buss	Marine Division
Capt. John Wilson	Marine Division

Richmond (CA) Fire Department

Battalion Chief M. Lynch

San Francisco Fire Department

Chief Andrew Casper	Chief of Department
Deputy Chief Emmett Condon	Deputy Chief of Department
Assistant Chief Robert Rose	Chief, Research and Planning

Seattle Fire Department

Capt. Robert Hansen

Tampa Fire Department

Capt. Carrero

Toledo Fire Department

Assistant Chief Getting

SHIPPING LINES

American Export Lines

Mr. George Kunz — Claims Manager

American President Lines

Mr. James Douglas
Mr. R. Moor
Mr. B. Rush

Chevron Shipping

Mr. Gerry Burr
Capt. Bain Leland — Training and Safety Officer

Exxon Shipping

Mr. E. D. Sprott — Chief Mate, The Exxon Newark

Farrell Lines

Mr. John Horner
Mr. Edward F. McIntyre — Director of Safety and Loss Prevention

Capt. O'Byrne

Johnson Lines

Capt. Hendrick Tegelberg

Lykes Bros. Lines

Capt. Owen Darnell — Assistant Manager, Accident Prevention

Capt. Clarence Wehrung — Manager, Accident Prevention

Matsun Lines

Capt. Hayden
Capt. Pollard

<u>Mobil Shipping and Transportation Company</u>

Mr. H. Aguero	Maintenance and Repair Supervisor

<u>Moore McCormack Lines</u>

Capt. Svend Madsen	Moore McCormack Bulk Transport
Mr. Ed Montgomery	Manager, Insurance and Claims Division
Capt. Dino Savastio	Marine Superintendent

<u>Pacific Far East Lines</u>

Capt. H. Ziobro

<u>Prudential Lines</u>

Mr. N. McGregor

<u>Sea-Land Services</u>

Mr. Roy Tolley

<u>States Lines</u>

Capt. Nelson

<u>United States Lines</u>

Mr. Edward Frank	Engineering

<u>West Coast Shipping Company</u>

Capt. Earl Mealins

REFERENCES

Written Material

A.B.S. Computers, Inc. Data on built-in fire suppression systems compiled by surveyors of the American Bureau of Shipping, September 1976 - September 1977.

American Hull Insurance Syndicate. Records of fires, explosions, and collisions resulting in fire, 1971-76.

Applied Technology Corporation. "Design Features of Liquefied Natural Gas Terminals," Norman, Oklahoma, March 1978.

Bauman, Richard A., Chief, Port Safety and Law Enforcement Division, Office of Marine Environment and Systems, USCG, "U.S. Coast Guard Participation in Marine Fire Fighting Operations," Marine Fire Protection Conference, Seattle, Washington, 9 June 1976.

Beer, W. J., "Analysis of World Merchant Ship Losses," a paper read at the meeting of the Royal Institution of Naval Architects, London, March 28, 1968.

Derry, Louis, "A Study of United States Fire Experience, 1976," Fire Journal, Vol. 71, pp. 50-53 (November 1977).

Ecker, William J., Commander, USCG, "Casualty Analysis of Selected Waterways," a paper for the Third International Symposium on Marine Traffic Service, Liverpool, England, April 3-6, 1978.

Flynn, Joseph A., Chief of Staff, Fire Department of New York, and Thomas J. Rush, Deputy Chief of the Marine Division, Fire Department of New York, "Marine Fire Protection Project Assessment."

de Frondeville, Bertrand, "Reliability and Safety of LNG Shipping: Lessons from Experience," The Society of Naval Architects and Marine Engineers, November, 1977.

Howard, R. A., "The Value of Life," unpublished manuscript, Stanford University, Stanford, California (1978).

Howard, R. A., J. E. Matheson, and D. L. Owen, "The Value of Life and Nuclear Design," SRI International, Menlo Park, California (1978).

Insurance Company of North America, "Ports of the World, A Guide to Cargo Loss Control," Tenth edition.

Japanese Maritime Safety Agency, "Report on the Outline of Collision Between Japanese Tanker Yuyo Maru No. 10 and Liberian Freighter Pacific Ares," November, 1974 (March 1975).

Linnerooth, J., "The Evaluation of Life-Saving: A Survey," joint IAEA/IIASA Research Report, International Atomic Energy Commission, Vienna, Austria.

Los Angeles (City) Department of Fire, "The Hazardous Cargo Task Force, Final Report," June 20, 1977.

Maritime Administration, "A Statistical Analysis of the World's Merchant Fleets" (December 31, 1975).

Maritime Administration, "U.S. Merchant Marine Data Sheet" (June 1, 1977).

Maritime Administration, Foreign Trade Information Systems, "Number and Percentage of U.S. and Foreign Flag Vessels Entering and Clearing U.S. Ports during Calendar Year 1976" (processed December 1977).

National River Academy, "Fire Fighting First Aid and Emergency Training Course," Helena, Arkansas.

New York City Fire Department, Division of Fire Control, "All Units' Circular #246: Marine Fires and Emergencies" (1977).

Nuclear Regulatory Commission, "Cost-Benefit Analysis for Radiowaste Systems for Light-Water Cooled Nuclear Power Reactors," Draft Regulatory Guide 1.FF, Washington, D.C. (1975).

Philadelphia Port Corporation, "Waterfront Facilities."

Rush, Thomas J., and Salvatore Valenza, "Fire Afloat," With New York Firemen, Volume 34, New York City Fire Department (1973).

Rushbrook, Frank, Fire Aboard, Simmons-Boardman Publishing Corporation, New York (1961).

San Francisco Fire Department, Division of Training, "Manual of Standard Practices for Fireboats, Ship, and Pier Fires" (1976).

Seattle Fire Department and the Washington State Commission for Vocational Education, "Report on the Marine Fire Protection Project" (August 31, 1976).

Sinclair, C. A., and C. Eng, "Causes of Fires in Ships," Royal Institution of Naval Architects/Institute of Marine Engineers Joint Symposium (1972).

Stannard, James H., Jr., "Thermal Radiation Hazards Associated with Marine LNG Spills," Fire Technology (February 1977).

Temple, Barker & Sloan, Inc., "A Study of the Future Requirements for Ships That Will be Engaged in the U.S. World Trade for Both the Short and Long Term," March 1, 1976.

U.S. Army Corps of Engineers, "Waterborne Commerce of the United States, Calendar Year 1975," Part 5, National Summaries.

U.S. Coast Guard, "Activities Relating to Title II Ports and Waterways Safety Act of 1972" (January 1977).

U.S. Coast Guard, "Automated Vessel Casualty System, Records of Commercial Vessel Casualties by Fire or Explosion, Fiscal Years 1963-76."

U.S. Coast Guard, "Automated Vessel Casualty System, Records of Commercial Vessel Casualties by Collisions with Vessels, Fiscal Years 1974-76."

U.S. Coast Guard, "Background and Summary Regarding the International Conference on Tanker Safety and Pollution Prevention Held in London, England, February 6-17, 1978" (March 24, 1978).

U.S. Coast Guard, "International Conference on Tanker Safety and Pollution Prevention, 1978," Working Paper containing Final Act of the Conference, with attachments including Protocols to SOLAS 74 and MARPOL 73 Resolutions adopted by the Conference (March 1, 1978).

U.S. Coast Guard, "Laws Governing Marine Inspection," July 1, 1975.

U.S. Coast Guard, "Liquefied Natural Gas: Views and Practices, Policy and Safety" (February 1976).

U.S. Coast Guard, Captain of the Port, Boston, Massachusetts, "LNG/LPG Contingency Plan" (June 15, 1974).

U.S. Coast Guard, "Marine Casualty Report: Collision Involving SS African Star and M/V Midwest Cities and Tow in Mississippi River on March 16, 1968" (released November 10, 1970).

U.S. Coast Guard, "Marine Casualty Report: Collision Involving SS Union Faith and M/V Warren J. Doucet and Tow in Mississippi River on April 6, 1969" (released December 22, 1970).

U.S. Coast Guard, "Marine Casualty Report: SS V. A. Fogg; Sinking in the Gulf of Mexico on 1 February 1972 with Loss of Life." Report No. USGC/NTSB-MAR-74-8 (1974).

U.S. Coast Guard, "Marine Casualty Report: Explosion and Fire on Board the Unmanned Tank Barge Ocean 80 at Carteret, New Jersey on 25 October 1972 without Loss of Life." Report No. USCG/NTSB-MAR-75-3 (1975).

U.S. Coast Guard, "Marine Casualty Report: SS C.V. Sea Witch - SS Esso Brussels (Belgium); Collision and Fire in New York Harbor on 2 June 1973 with Loss of Life." Report No. USCG/NTSB-MAR-75-6 (1975).

U.S. Coast Guard, "Marine Casualty Report: SS Texaco North Dakota; Explosion and Fire in the Gulf of Mexico on 3 October 1973 with Loss of Life." Report No. USCG/NTSG-MAR-75-5 (1975).

U.S. Coast Guard, "Marine Casualty Report: SS Keytrader and SS Baune (Norwegian); Collision in the Mississippi River on 18 January 1974 with Loss of Life." Report No. USCG/NTSB MAR-77-1 (1977).

U.S. Coast Guard, "Marine Casualty Report: M/V Elias; Explosion, Fire, and Sinking in the Delaware River on April 9, 1974 with Loss of Life" (released July 19, 1977).

U.S. Coast Guard, "Marine Casualty Report: SS Transhuron; Stranding at Kiltan Island on 26 September 1974 without Loss of Life." Report No. USCG/NTSB MAR-76-2 (1976).

U.S. Coast Guard, "Marine Casualty Report: SS Edgar M. Queeny and S/T Corinthos; Collision at Marcus Hook, Pennsylvania on 31 January 1975 with Loss of Life." Report No. USCG/NTSB-MAR-77-2 (1977).

U.S. Coast Guard, "Marine Casualty Report: Tank Barge B-924; Explosion and Fire on Board at Greenville, Mississippi on 13 November 1975 with Loss of Life." Report No. USCG 16732/63662 (July 26, 1977).

U.S. Coast Guard, "Marine Casualty Report: SS Sansinena (Liberian); Explosion and Fire in Los Angeles, California Harbor on 17 December 1976 with Loss of Life." Report No. USCG 16732/71895 (1976).

U.S. Coast Guard, "Marine Terminal and Vessel Accident Plan, San Francisco Bay and Delta Regions" (1977).

U.S. Coast Guard, Office of Merchant Marine Safety, "Statistics of Casualties, 1977" (March 1978).

U.S. Coast Guard, "Tanker Safety and Pollution Prevention," Federal Register, Part II (April 20, 1978).

U.S. Coast Guard, "Tankerman Requirements: Qualifications of Persons in Charge of Oil Transfer Operations," Federal Register, Part II (April 25, 1977).

U.S. Coast Guard, Study Report, "Vessel Traffic Systems, Analysis of Port Needs" (August 1973).

U.S. Department of Commerce, Bureau of the Census, United States Foreign Trade: "Vessel Entrances and Clearances," 1976 Annual Report (August 1977).

U.S. Congress, H.R. 11459, "A Bill to Amend the Merchant Marine Act of 1936 in order to Establish a National Marine Firefighting Program" (January 22, 1976).

U.S. Department of Transportation, "1975 Societal Costs of Motor Vehicle Accidents," Washington, D.C. (1976).

U.S. Department of Transportation, "Federal Port Policy in the United States." Report No. DOT-TST-77-41, Washington, D.C., Final Report (June 1977).

Welker, J. R., et al., "Fire Safety Aboard LNG Vessels," University Engineers, Inc., Norman, Oklahoma (January 1976).

World Almanac, 1977, "Commerce at Principal North American Ports."

☆U.S. GOVERNMENT PRINTING OFFICE: 1979-281-067/73